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Dr Ani Raidén
Nottingham Business School
Nottingham Trent University
Burton Street
Nottingham NG1 4BU
Email: ani.raiden@ntu.ac.uk

ARCOM Declaration:

The papers in these proceedings were double-blind refereed by members of the scientific committee in a process that involved, detailed reading of the papers, reporting of comments to authors, modifications of papers by authors and re-evaluation of re-submitted papers to ensure quality of content.

FOREWORD

Welcome to the 31st Annual Association of Researchers in Construction Management (ARCOM) conference. As we settle into the new decade of activities, ARCOM has extended the online provision of materials and embraced international collaboration. For the first time, we have prepared a 'live programme'. This is an interactive version of the conference programme, available via MyARCOM (https://secure.arcom.ac.uk/view_prog_whole.php?id=24). We will use this tool to provide up-to-date information about the conference and give access to the papers being presented in Lincoln online.

As the world of research becomes increasingly digitised and our conference proceedings are less often read in hard copy form, it felt that the papers weren't perhaps getting the same attention they once were. At the time when a hard copy of the conference proceedings was accessible to all delegates, many browsed and read papers during the sessions to find additional information while others perused the proceedings to seek interesting presentations to attend. Often delegates did a bit of both! I wanted to bring back this easy access to the full papers. The authors whose papers are included in these proceedings have worked very hard, in many cases years, to conduct the research they publish here, and so their work should be available, in full, to all at the conference. ARCOM provides an open access source for the conference proceedings and the abstracts of several leading construction management journals and PhD theses within the CM Abstracts database (<http://www.arcom.ac.uk/abstracts.php>). We will continue to provide all year round access to relevant publications in the field. We hope that this new tool, the 'live programme', will help you navigate your way through the many parallel and plenary sessions, and smoothly access the full papers via MyARCOM during the conference.

In these proceedings we present the rich variety of contributions to the conference. This year our delegates come from 33 different countries with a diverse range of backgrounds, interests and expertise. Sustainability; planning, productivity and quality; building information modelling; and health, safety and well-being continue to draw a large number of submissions. Procurement and risk management also feature as important themes in the conference, together with house building which is increasingly popular topic. Decision-making modelling emerges as a new area of interest.

We present to you 127 papers that were accepted for publication. This is the result of an intense three-stage double-blind review process through which we have been able to maintain high quality standards. Our initial call led to an astonishing 357 abstracts and 192 full papers being submitted. The Scientific Committee have worked very hard to select the final papers for presentation. If your paper is included in these proceedings then you should feel very proud of your achievement!

In addition to the research papers we welcome to the conference our keynote speakers and debate panellists: Professors John Connaughton, University of Reading; Alan Penn, The Bartlett, University College London; Martin Loosemore, The University of New South Wales, Australia; and Deborah Pullen, Building Research Establishment. The debate will address: *'This house believes that the widespread insistence on justifying investment in research with reference to the 'business case' inevitably perpetuates current modes of working and hence hinders innovation.'*

The Langford Lecture this year will be presented by Jemma Bridgeman from Construction Youth Trust, Cymru. And, as a follow on from the debate on method in

Portsmouth last year during the 30th Annual ARCOM Conference, we are most pleased to introduce a new Spotlight session on Comparative Studies. Professors Henrik Linderöth, Jönköping University, Sweden, and Chris Harty, University of Reading, will chair this discussion of comparisons by country, industry, stakeholder, competences, task, and process.

Putting together the academic programme for the conference is a collective effort, and I thank the ARCOM committee and wider Scientific Committee for their voluntary contribution to making the conference such a success year after year. David Boyd, Paul Chan, Scott Fernie, Chris Harty and Simon Smith in particular have been instrumental in supporting the planning and managing of the conference over the past eight months.

I wish you an enjoyable and inspiring three days in Lincoln; enjoy the diversity of research presented at the conference and proceedings and make the most of the many networking events.

Ani Raidén, ARCOM 2015 Conference Chair, Nottingham Trent University, UK
On behalf of the ARCOM Committee

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A MATHEMATICAL MODEL FOR ALLOCATING PROJECT MANAGERS TO PROJECTS

Lone Seboni¹ and Apollo Tutesigensi

Institute for Resilient Infrastructure, School of Civil Engineering, University of Leeds, Woodhouse Lane, Leeds, LS2 9JT, UK

In multi-project environments, the decision of which project manager to allocate to which project directly affects organizational performance and therefore, it needs to be taken in a fair, robust and consistent manner. We argue that such a manner can be facilitated by a mathematical model that brings together all the relevant factors in an effective way. Content and thematic analyses of extant literature on optimization modelling were conducted to identify the major issues related to formulating a relevant mathematical model. A total of 200 articles covering the period 1959 to 2015 were reviewed. A deterministic integer programming model was formulated and implemented in OpenSolver. The utility of the model was demonstrated with an illustrative example to optimize the allocation of six project managers to six projects. The results indicate that the model is capable of making optimal allocations in less than one second, with a solution precision of 99%. These results compare well with some intuitive verification checks on certain expectations. For example, the most competent project manager was allocated to the highest priority project while the least competent project manager was allocated to the lowest priority project. Through this study, we have proposed a comprehensive and balanced approach by incorporating both hard and soft issues in our mathematical modelling, to address gaps in existing project manager-to-project (PM2P) allocation models as well as extending applications of mathematical modelling of the PM2P allocation problem to a “new” country and industry, with a view to complement managerial intuition. In an attempt to address gaps in existing mathematical models associated with challenges related to acceptance by industry practitioners, future work includes developing a graphical user interface to separate the model base and optimization software details from users, as part of a complete product to be validated as an industry application.

Keywords: integer programming, mathematical modelling, multi-project environment, project manager.

INTRODUCTION

Allocation of project managers to projects (PM2P) is an important topic because of the significant impact of this decision on project success. This view has been demonstrated by seminal work of authors such as (Brown and Eisenhardt, 1995; Pinto and Slevin, 1988), who are all unified in concluding that the choice of a project manager is one of the critical factors that influence project success. Approaches to improve allocation decisions and get them right first time have become necessary to achieve project success. Other authors have built on the seminal work of these earlier authors, in relation to proposing approaches to improve the PM2P allocation process, given empirical evidence of a lack of formal and effective management tools to improve this process (Patanakul *et al.*, 2007; Choothian *et al.*, 2009). Several

¹ mnl@leeds.ac.uk

approaches have been proposed and include either informal approaches (e.g., managerial intuition) or formal optimization-based approaches. LeBlanc *et al.* (2000) provides evidence of the ineffectiveness of managerial intuition for assigning managers to construction projects. Optimization-based approaches, using mathematical modelling techniques, stand out in terms of superiority to informal approaches, on the basis of capability to handle a large number of decision variables concurrently, yielding a less subjective and more optimized decision that considers all variables in less time (Mason, 2011; Meindl and Templ, 2012). For example, the human mind cannot handle many decision variables, all at the same time and arrive at an optimum decision faster than optimization-based approaches, due to limited capacity for both memory and arithmetic (Adair, 2007). Whilst there are benefits with optimization based approaches that use spreadsheet modelling, critical analysis of spreadsheet models (see LeBlanc *et al.*, 2000; Ragsdale, 2015), reveals problems of lack of flexibility associated with having to make changes in different parts of the spreadsheet and limits on number of variables to be processed. Algebraic mathematical modelling, using functions in conjunction with optimization software, addresses these limitations and produces solutions in less time compared to using spreadsheets (Mason, 2011; Meindl and Templ, 2012).

However, there are limitations in existing mathematical modelling, using optimization software. For example, there is a lack of consideration of soft issues in the modelling, to yield a comprehensive and balanced approach in relation to both hard and soft issues. We have modelled both hard and soft issues in terms of additional and significant factors that influence the PM2P allocation decision. For example, we have included additional variables that represent reality in relation to PM2P allocation intensities that indicate variations in workloads. The modelling of allocation intensities, derived from distances between project sites and project manager locations (an important influencing factor) has not been included in existing models (e.g., Patanakul *et al.*, 2007; Choothian *et al.*, 2009).

These additions represent a major advantage of our proposed model over existing models, in relation to equations that model both hard and soft issues. For example, the modelling of PM2P allocation intensities reveals variations in workloads for each project manager, which better informs the allocation process in terms of fairness (LeBlanc *et al.*, 2000). However, mathematical model outputs are a guideline to aid managerial decision making, with a view to reduce subjectivity in the PM2P allocation process. The contribution of the model is that it gives an optimum solution, having concurrently considered all the important decision variables that a practitioner could not have considered all at the same time, given a human decision maker's limited cognitive ability (Adair, 2007). Furthermore, our model addresses limitations in prior models by increasing the flexibility of making changes, including the modelling of additional variables that have been verified in literature (Seboni and Tutesigensi, 2014), as important influencing factors to the PM2P practice.

Overall research approach and scope

The overall research approach can be divided into two parts namely: data gathering about the PM2P problem and mathematical formulation and verification (Figure 1).

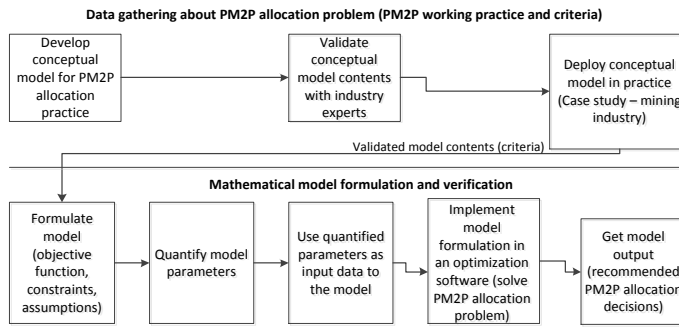


Figure 1: Overall research approach

The scope of this study is on mathematical model formulation and verification. This includes: formulating the model, quantifying parameters and using them as input data to the model, implementing the model formulation in an optimization software to verify functionality, using input data, and interpreting the output. Items in the scope for this study are illustrated in the bottom half of Figure 1. The top half of Figure 1 is out of scope and is the subject of a previous study involving development and verification of a conceptual model for the PM2P practice, in relation to important factors influencing the PM2P allocation decision (Seboni and Tutesigensi, 2014).

In terms of context regarding the top half of Figure 1, a total of 37 factors that influence the PM2P allocation process were identified from critical reviews of both the depth and breadth of literature surrounding the PM2P allocation process. These 37 factors were: organization's mission, goals, projects, contribution of goals to mission, contribution of projects to goals (under project prioritization); project manager competencies, project characteristics, project manager's personal preferences, number of projects, number of project managers, project manager category, project type, performance on previous projects (under PM2P matching); organization's resource capacity, project manager availability, location of project, location of project manager, project phase mix, project type mix, project team strength and availability, project team dispersion, re-allocation effectiveness of each project manager, degree of trust on project manager, decision maker's personal preferences and prejudices, fixed allocations, special requirements, project interdependencies, project manager's personality, organization's rules and regulations, decision maker's personal interests, project manager's age, gender, marital status, health condition, nationality and religious beliefs. See (Seboni and Tutesigensi, 2014) for details of these 37 factors.

The current paper is a continuation from a previous paper, in the context of modelling the identified list of factors that have been verified to influence the PM2P allocation process. The modelling of the 37 factors addresses the established challenges faced by practitioners in terms of a lack of formal and effective management tools to aid allocation decisions (Patanakul *et al.*, 2007; Choothian *et al.*, 2009), given practitioners' reliance on intuition, which has been established to be ineffective (LeBlanc *et al.*, 2000; Patanakul *et al.*, 2007). Managerial intuition also impacts negatively on organizational performance (Patanakul *et al.*, 2007). The modelling includes both hard and soft issues in the allocation, contrary to existing models, to strike a balance in terms of a representation of reality. For example, project manager's personal preferences, decision maker's personal preferences and prejudices were included, in line with achieving a near representation of reality (Burghes and Wood, 1980). The proposed model is a guideline to complement managerial intuition in PM2P allocations. Both the manager's intuition regarding the allocation decisions, together with the output from the model, constitute an effective PM2P allocation process.

METHODOLOGY

Content and thematic analysis of extant literature on mathematical modelling (e.g., classification and types of models, concepts of mathematical modelling and application areas, including use of optimization software to implement the model base) were conducted. Appropriate principles involved in formulating mathematical models were then adopted in the development of a model for this study.

Firstly, a deterministic approach was chosen over a stochastic approach, on the basis of aspects of certainty in estimations (e.g., project manager availability and competency levels), as opposed to a stochastic approach characterized by uncertainties due to randomness (Murthy *et al.*, 1990). This approach is consistent with existing models (e.g., Patanakul *et al.*, 2007; Choothian *et al.*, 2009) on this type of allocation problem. Secondly, assumptions of a static system in relation to assessing project managers and projects at a snapshot in time (e.g., Choothian *et al.*, 2009), warrant the use of algebraic equations in the mathematical formulation over other equation types (e.g., differential and integral), on the basis of suitability of algebraic formulations for static systems. For example, Murthy *et al.* (1990) advocates for static and algebraic expressions in the formulation of deterministic models. Thirdly, since the emphasis of this study was aimed at proposing a mathematical model to quantify the PM2P allocation process, it follows that a quantitative approach is more appropriate over a qualitative approach (Saaty and Alexander, 1981). Lastly, given the nature of the PM2P allocation problem, in which the decision variables can be expressed by linear equations but restricted to integers, integer linear programming was chosen over non-linear programming (Ragsdale, 2015).

Mathematical formulation of the PM2P allocation problem and assumptions

The task was to formulate a model and conduct a demonstration project to solve an allocation problem involving determination of an optimum PM2P allocation decision associated with allocating six project managers to six projects, using the context of a case organization in Botswana. The organization's operations include implementing construction and underground mineral exploration projects in a mining industry. This organization has three geographic locations in relation to project sites and the project managers can be allocated to any project in these three sites, hence inclusion of PM2P allocation intensities. The notation used in the formulation and the mathematical formulation of the PM2P allocation problem are presented in Figures 2 and 3 respectively. The following assumptions were made (Patanakul *et al.*, 2007; Choothian *et al.*, 2009):

1. Assessments of project managers and projects are made at a specific time (static system), consistent with existing models;
2. The PM2P allocation decision is made at a specific snapshot in time;
3. All project managers are full-time and there are no part-time project managers since overhead time is not applicable for part-time project managers; and
4. A decision maker can express his/her judgement regarding the performance of each individual alternative, relative to each alternative (Triantaphyllou, 2000). This implies measuring in relative rather than absolute terms, which is not problematic given the following quote: "*it is difficult, if not impossible, to quantify*" (p.23) qualitative attributes, which explains why "*many decision making methods attempt to determine the relative importance of the alternatives in terms of each criterion in a given MCDM problem*" (p.23). This

statement supports the view that it is easier to quantify data required to solve a MCDM problem in relative terms rather than absolute terms.

Decision variables: $[A_{ij}]$ Index set to indicate the allocation of project manager i to project j ;

Data/parameters: i subscript for the i^{th} project manager; j subscript for the j^{th} project; k subscript for the k^{th} goal, $[w_i]$ Index set for the intensity of allocating project manager i to project j ; $[s_i]$ Index set for the suitability of project manager i to project j ; $[g_k]$ Index set for the relative contribution of goal k to accomplishment of the organization's mission; $[p_k]$ Index set for the relative contribution of project i to goal k ; $[e_k]$ Index set for the extent of effectiveness of project manager i to manage the discontinuity of project j 's contribution to goal k ; t subscript for the time period to indicate the months in which the project is active or inactive; $[M_i]$ Index set for the maximum allowable intensity of allocating project manager i to project j in time period t ; $[m_i]$ Index set for the minimum allowable intensity of allocating project manager i to project j in time period t ; $[d_j]$ Index set for the individual time demand of project j on project manager i ; $[l_i]$ Index set for the loss in productivity of project manager i due to managing multiple concurrent projects; $[T_i]$ Index set for the time availability of project manager i ; $[n_i]$ Index set for the number of existing projects managed by project manager i ; $[N_i]$ Index set for the maximum allowable number of concurrent projects managed by project manager i ; M_i maximum number of allowable projects that project manager i can manage effectively; $[F_i^c]$ current/existing projects in feasibility and post completion audit phase managed by project manager i ; $[F_i^m]$ maximum number of projects in feasibility and post completion audit phase that project manager i can effectively manage concurrently; $[G_i^c]$ current/existing geotechnical drilling types of projects managed by project manager i ; $[G_i^m]$ maximum number of geotechnical drilling projects that project manager i can effectively manage concurrently; a_j^t binary variable to determine if project j is active in period t ; F_j binary variable to determine if the candidate project is in feasibility and post-completion audit phase; G_j binary variable to determine if the candidate project is a geotechnical drilling type of project.

Figure 2: Notation

Maximize: $\sum_{i=1}^I \sum_{j=1}^P \sum_{k=1}^O (w_i e_k g_k p_k s_j A_{ij}) \dots \dots \dots (1)$

Subject to the following constraints:

Time availability: $\sum_{j=1}^P d_j A_{ij} + l_i \leq T_i \quad \forall i \dots \dots \dots (2)$

Total number of concurrent projects: $N_i = \sum_{j=1}^P A_{ij} + n_i \quad \forall i \dots \dots \dots (3)$

Maximum allowable number of projects: $\sum_{j=1}^P A_{ij} + n_i \leq M_i \quad \forall i \dots \dots \dots (4)$

PM2P allocation intensity: $m_i \geq [(w_{ij}^* a_j^t) A_{ij}] \leq M_i \quad \forall i \dots \dots \dots (5)$

Project phase mix: $\sum_{j=1}^P F_j A_{ij} + F_i^c \leq F_i^m \quad \forall i \dots \dots \dots (6)$

Project type mix: $\sum_{j=1}^P G_j A_{ij} + G_i^c \leq G_i^m \quad \forall i \dots \dots \dots (7)$

Fixed PM2P allocations: $A_{ij} = 1 \quad \forall i, \text{ where } j \in [\text{fixed PM2P allocations}] \dots \dots \dots (8)$

Prohibited allocations: $A_{ij} = 0 \quad \forall i, \text{ where } j \in [\text{prohibited allocations}] \dots \dots \dots (9)$

Special requirements: $\sum_{i=1}^I (p_j^c) A_{ij} = 1 \quad \forall j, \text{ where } j \in [\text{projects requiring special competencies}] \dots \dots \dots (10)$

Project interdependencies: $A_{ij} = A_{ib} \quad \forall i, \text{ where } (j \text{ and } b) \in [\text{a set of projects such that project manager } i \text{ must be allocated to those set of projects}] \dots \dots \dots (11)$

Only one project manager per project: $\sum_{i=1}^I A_{ij} \leq 1 \quad \forall j, \dots \dots \dots (12)$

No idling project manager: $\sum_{j=1}^P A_{ij} \geq 1 \quad \forall i, \dots \dots \dots (13)$

Binary variables: A_{ij}, F_j, a_j^t and G_j must be binary. $\dots \dots \dots (14)$

Figure 3: Mathematical formulation

Quantification of model parameters

A brief discussion of the quantification of parameters for the PM2P allocation process is presented under the three processes namely: project prioritization, PM2P matching and recognition of constraints.

Project prioritization

To quantify parameters in the project prioritization process (objective function parameters), we utilized the analytic hierarchy process (AHP) developed by Saaty (Saaty, 1980), to break down the process into three hierarchical levels. The nature of the PM2P allocation process, in terms of the large number of decision variables, makes it a complex multi-criteria decision making problem that suits the use of AHP (Triantaphyllou, 2000). Level 1 was the mission of the organization, level 2 was the organization's goals and level 3 was the projects. We then deployed the constant sum method (Kocaoglu, 1983) by performing pairwise comparisons of level 2 to level 1 elements (Goals-To-Mission matrix) and level 3 to level 2 elements (Projects-To-Goals matrix). Matrix multiplication of these two matrices yielded the overall contribution of each project (relative to other projects) to the accomplishment of the mission (i.e., project priorities). This approach is consistent with existing studies (e.g., Patanakul *et al.*, 2007 and Choothian *et al.*, 2009).

Re-allocation effectiveness of each project manager - the parameter, e_{ijk} (see notation and equation 1), indicates the ability of a project manager to take over an existing project from its current project manager, in the event of a “re-allocation”, to accommodate the dynamic reality of the business environment in terms of incoming projects. This parameter was quantified using a scale from 0 to 100%, where, 0% and 100% indicate ineffectiveness and effectiveness (respectively). There are two conditions in which a score of 100% can be given: (1) if the project manager is allocated to a new incoming project, and (2) if the project manager is allocated to his/her existing project, following a reshuffling.

PM2P allocation intensities - the quantification of this parameter is based on input data regarding: driving times (hours) between project managers' location and project sites, average trip frequencies over the project duration and project costs. The PM2P allocation intensities for each project manager are then computed (behind the scenes) and linked to the decision variables in the formulation, such that the optimization software considers this parameter (along with all other parameters, all at the same time) in its search for the optimum PM2P allocation decision.

The quantification of parameters is subjective, given the intangible nature of the decision criteria to be evaluated. The contention is that, through mathematical modelling of the PM2P allocation process, involving intangible criteria that are often evaluated using managerial intuition (informal), we provide a formal process. This formal process uses a carefully designed measurement instrument that quantifies all parameters in a less subjective manner, compared to managerial intuition, considered ineffective (LeBlanc *et al.*, 2000) due to limited cognitive ability of a human mind.

PM2P matching

To quantify parameters in the PM2P matching process, we collected data from a previous study (Seboni and Tutesigensi, 2014) regarding rating scores for available project manager competencies (matrix 1) against 21 required competencies (matrix 2), measured on a Likert scale (1 = very low, 5 = very high). Matrix 1 involved measuring the 21 competencies against six candidate projects in terms of project characteristics (i.e., required competencies). Matrix 2 involved measuring the same 21

competencies against six candidate project managers (i.e., available competencies). The 2 matrices were then multiplied together to obtain a matching score between candidate project manager competencies (available competencies) and candidate projects (required competencies). The difference between the resulting output (available competency minus required competency) was then inspected and a coding scheme applied to interpret the individual matching scores. For example, a difference of zero was coded as a “1” to reflect a perfect match. A difference of a positive number was coded as a “1.5” to reflect that the project manager's competencies are higher than what the project requires. However, a difference of a negative number was coded as a “0” to reflect that there is no match since the project manager's competencies are lower than what the project requires. To accommodate the practice at the case organization, a difference of negative one was coded as a “0.5” to indicate that the project manager's competencies are one unit below what the project requires. For this situation, an allocation may be made to accommodate project manager development or personal preferences. The coding scheme applied has an offsetting effect in cases where a project manager possesses higher or lower competencies than what the project requires, given that the overall PM2P matching score was computed from the sum product of two matrices (Patanakul *et al.*, 2007). It follows that the resulting PM2P matching score indicates the extent of match between each project manager's competencies and each project's requirements and expresses the suitability of each project manager relative to other project managers, for a given project.

Recognition of constraints

The parameters in the list of constraints are already in the form of values used as input data to the model. The relevant input data such as: project manager time availability and project time demand (man-hours per time period), is estimated by the decision maker on the basis of project characteristics as defined by the decision criteria (e.g., project complexities, durations and categories of projects). Given the dynamic nature of some of this data, the decision maker may need to consult the project managers at that specific time, including any existing records updated frequently.

Use of quantified parameters as input data to the model

Once all the parameters in the mathematical formulation were quantified, these become input data to the model. The execution of the model, using OpenSolver optimization software (Mason, 2011) to run the algorithm, considers all input data.

Implement model formulation in an optimization software

OpenSolver (an open source optimization package) was chosen to implement the model base, once built on a spreadsheet. Justification for using OpenSolver is that, besides no licensing fees, OpenSolver allows flexibility to shift the mathematical model (sitting on a spreadsheet) to other solver engines in terms of platform and architecture (Mason, 2011; Meindl and Templ, 2013).

Verification

The proposed model was subjected to a rigorous verification process in relation to two aspects: (1) dimensional homogeneity of all equations in the mathematical formulation (Berry and Houston, 1995), to ascertain that all parameters in the equations have the same dimensions, (2) use of different data sets (i.e., scenarios) as input data to solve the model and examine corresponding outputs in relation to 'expected' allocations as per intuitive checks (see Figure 4). The use of different data sets formed the basis of testing the model's robustness to different scenarios. For example, we used secondary

source input data from an existing study (Patanakul *et al.*, 2007), where appropriate, as an additional verification exercise to test the applicability of our proposed model.

Overview of methodological stance for other contexts

From a generic perspective, a methodology for applying the mathematical model in PM2P working practices of other organizations (subject to contextual factors) is presented in six steps (Patanakul *et al.*, 2007; Ragsdale, 2015; Triantaphyllou, 2000):

1. Understand the PM2P problem to be solved;
2. Formulate the mathematical model based on step 1;
3. Quantify parameters in the PM2P allocation problem in question;
4. Use quantified parameters as input data to the mathematical model;
5. Implement the model formulation in an optimization software; and
6. Verify model output (iterative process that may involve going back to step 1 until output is satisfactory).

RESULTS AND DISCUSSION

Based on input data used in our model to solve the PM2P allocation problem pertaining to the allocation of six project managers to six projects, the output from OpenSolver is displayed in Figure 4.

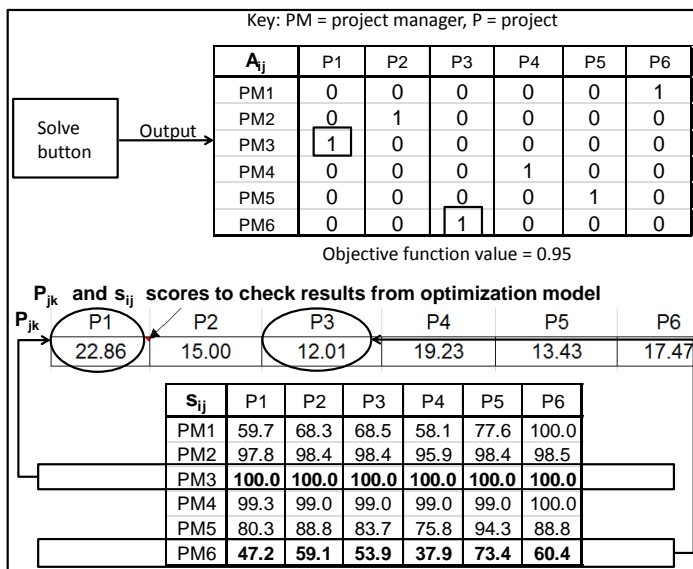


Figure 4: Model output

This output is a result of the OpenSolver engine, running the algorithm to search for a feasible and optimum solution to the PM2P allocation problem, on the basis of the model base (as presented in the formulation) and input data to this model. If the OpenSolver engine does not find a feasible and optimal solution to the problem, it displays an error message as the output. However, if the OpenSolver engine finds a feasible and optimal solution, it displays the output shown at the top of figure 4. For example, the OpenSolver engine recommends allocating project managers 1, 2, 3, 4, 5, and 6 to projects 6, 2, 1, 4, 5 and 3 respectively. This optimum solution occurs at an objective function value of 0.95, the maximum value for this problem.

The results indicate that our model is capable of making optimal PM2P allocations in less than one second, with a solution precision of 99%. This means that there is a 1% chance that the OpenSolver engine will not find an optimum solution to the problem, owing to the practical limitations of the open source software in relation to the number

of variables it can handle. These results compare well with some intuitive verification checks on certain expectations (see bottom of Figure 2). For example, project manager 3 (the most competent project manager because his/her matching scores for all projects was a maximum value of 100) was allocated to project 1 (the highest priority project, which contributes 22.86% to the accomplishment of the organization's mission, relative to other projects). Similarly, project manager 6 (the least competent project manager whose matching scores were the lowest across the board) was allocated to project 3 (the lowest priority project).

CONCLUSIONS AND FUTURE RESEARCH

Through this study, we have proposed a comprehensive and balanced approach by including both hard and soft issues in our model, to address gaps in existing models (e.g., Choothian *et al.*, 2009; LeBlanc *et al.*, 2000; Patanakul *et al.*, 2007). The modelling of additional qualitative variables that influence the PM2P allocation decision represents a contribution to existing models. We have extended applications of mathematical modelling of the PM2P allocation problem to a “new” country (Botswana) and industry (mining), by customizing our model to the context of an organization implementing construction and underground mineral exploration projects. This application area was hitherto, absent in extant literature prior to our study.

Limitations

The quantification of parameters is subjective. However, given a common measurement scale, the subjectivity of the PM2P allocation process is improved, relative to informal processes. The quantification can be improved as follows: using several informants to do the ranking, inspecting the internal inconsistencies and group disagreements among the informants, repeating the ranking as appropriate through several iterations until both internal inconsistencies and group disagreements are less or equal to 10% (Saaty, 1980). However, the nature of the informants (project, programme or portfolio directors) in any one organization is such that they are few.

Implications

The implications of our study are evidenced by Skabelund (2005), who found that twenty-seven percent of a manager's time as well as annual costs amounting to \$105 billion are lost on rectifying mismatches in allocations, arising from unsuitability of employees to tasks. Given the challenges faced by human decision makers (Patanakul *et al.*, 2007) in relation to limited capacity to process a large number of decision criteria, all at the same time (Adair, 2000) and in a less subjective manner, the outcomes of this study can be used to improve decision making, once implemented as a user-friendly industry application (see future research).

Future research

In an attempt to address gaps in existing mathematical models associated with challenges related to acceptance by industry practitioners, who may not understand the rigorous discourse of mathematical optimization modelling, future work includes developing a graphical user interface (GUI) as part of a complete decision support system to be validated as an industry application. We are able to report that this work has been completed through a case study approach to validate the developed application. The outcome of the evaluation of the complete product provided compelling evidence of its value, in comparison with the status quo, on the basis of 8 key variables used to test both the technical and practical solution to the PM2P

allocation problem of a specific organization. Potential to commercialize the product also emerged from the evaluation of the developed application.

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TIME-COST-QUALITY TRADE-OFF MODEL FOR SUBCONTRACTOR SELECTION USING DISCRETE PARTICLE SWARM OPTIMIZATION ALGORITHM

Befrin Neval Bingol¹ and Gul Polat

Faculty of Civil Engineering, Istanbul Technical University, Istanbul, Turkey

In general, construction projects consist of several work packages. The general contractors usually tend to sublet these work packages to various subcontractors. In such cases, general contractors are responsible for the quality of the work packages performed by the selected subcontractors. In this context, the success of a construction project and thereby the general contractor depends on the performances of the subcontractors. Therefore, one of the main problems that a general contractor faces is the selection of the right subcontractors for the right work packages. In most cases, general contractors make this decision at the beginning of the project and they have to evaluate potential subcontractors' performances in terms of time, cost and quality during the subcontractor selection process. After this evaluation process, they select an optimal combination of subcontractors that will carry out the work packages in the project. It is not an easy task for a general contractor to select the most appropriate combination, which balances the trade-off between time, cost and quality. The main objective of this study is to generate a discrete particle swarm optimization algorithm (DPSO), which will assist general contractors to select the most appropriate subcontractors that will carry out different work packages in a construction project considering the trade-off between time, cost and quality. In order to illustrate how this algorithm can be used in the subcontractor selection problem, the data obtained from a trade centre project is used. Findings of the research revealed that the proposed algorithm is satisfactory.

Keywords: subcontractor selection, time-cost-quality trade-off, discrete particle swarm optimization.

INTRODUCTION

Nowadays, general contractors usually prefer to act as construction management agencies. They generally win the contract, subdivide the tasks that need to be completed in the project into main work packages, and contract these work packages out to different subcontractors. The actual production work is carried out by subcontractors, whereas the general contractors are responsible for organizing, controlling and coordinating the works of the selected subcontractors. Since the general contractors are directly responsible for the quality of the works performed by the subcontractors to the owner/client, the subcontractors play critical role in the overall performance of the project and thereby the success of the general contractor.

Subletting large portions of construction activities to subcontractors promise several benefits to general contractors, such as; 1) reduced liability for labour retention as well as reduced overheads, especially during periods of low construction activity; 2) risk

¹ nevalbingol@gmail.com

sharing arrangements with subcontractors for their specific work packages; 3) higher quality and productivity from a core of people engaged in specialist work packages; and 4) better cost control through fixed-price subcontracting (CIDB, 2013). In spite of these benefits, subcontracting is also very risky practice as it requires the coordination of subcontractors, control of the quality and progress of subcontractors' works (Karim *et al.*, 2006; Ng *et al.*, 2009; Cooke and Williams, 2013).

In practice, general contractors usually tend to select their subcontractors after they sign the contract with the owner at the very beginning of the project or when the specific tasks to be done by the subcontractor get closer. Therefore, general contractors usually do not have adequate time to evaluate and select subcontractors in a realistic way. General contractors select their subcontractors based on two traditional approaches, which are: selecting the subcontractor, who offers the lowest bid price (Tserng and Lin, 2002; Mbachu, 2008; Hartmann *et al.*, 2009) or selecting the subcontractor whom they know from previous projects (Tserng and Lin, 2002; Ulubeyli, *et al.*, 2010; Choudhry *et al.*, 2012). Selecting the subcontractors based on only the lowest the bid price criterion may bring about severe problems such as; employing unskilled, inexperienced, and financially inadequate subcontractors. On the other hand, working with the known subcontractors may result in problems in cost control; usage of new technologic innovations; and negotiation processes (Tserng and Lin, 2002). Therefore, general contractors should consider several criteria when they select their subcontractors.

In the construction management literature, there are a great number of valuable studies that deal with subcontractor selection problem. The common point of these studies is that they all focus on selecting the most appropriate subcontractor for one work package in the project. However, in real life, general contractors usually divide construction projects into major work packages and sublet most/all of these work packages to the subcontractors, who are selected through bidding or negotiation. Since the overall performance of the project is directly affected by the performances of the subcontractors, who undertake different work packages in the construction project, the interactions between all subcontractors should be considered during the subcontractor selection process. The main contribution of this study is that it considers the subcontractor selection process as a time-cost-quality trade-off problem and takes into account the interactions between the subcontractors, who are in charge of carrying out different work packages in the project, during the subcontractor selection process. This study proposes a multi objective optimization model, which aims to assist general contractors in selecting the most appropriate subcontractors. The selection model aims to optimize the time, cost and quality performances of the subcontractors. In the proposed model, discrete particle swarm optimization algorithm (DPSO) is employed.

PREVIOUS WORKS ON TIME-COST-QUALITY TRADE-OFF PROBLEM

Time, cost and quality are three conflictive objectives. It is even hard to provide compromise solutions between these objectives. In the construction management literature, several researchers (Khang and Myint, 1999; El-Rayes and Kandil, 2005; Pollack-Johnson and Liberatore, 2006; Afshar *et al.*, 2007; Tareghian and Taheri, 2006, 2007; Rahimi and Iranmanesh, 2008; Zhang and Li, 2010; Zhang and Xing, 2010; Zhang *et al.*, 2013; Mungle *et al.*, 2013; Heravi and Faeghi, 2014; Tavana *et al.*, 2014) made significant efforts to solve the time-cost-quality trade-off problem in the

construction projects. The solution methods employed in these studies can be categorized into three main groups, namely (1) mathematical algorithms, (2) heuristic algorithms, and (3) evolutionary algorithms. Among these groups, evolutionary algorithms are the most favourable one because of the fact that they are capable to deal with more than one objective, easily achieve diverse solutions and better in complex problems compared to the other algorithms. Genetic algorithm (El-Rayes and Kandil, 2005; Mungle *et al.*, 2013; Tavana *et al.*, 2014), particle swarm optimization (Zhang and Xing, 2010), ant colony algorithm (Afshar *et al.*, 2007), and electromagnetic scatter search (Tareghian and Taheri, 2007) are some of evolutionary algorithms used in time-cost-quality trade-off problem.

RESEARCH METHODOLOGY

Particle swarm optimization

Particle swarm optimization (PSO) is a population based stochastic optimization technique, which is commonly used to search an optimal solution in the search space. It was first developed by Eberhart and Kennedy (1995). This optimization technique is a kind of swarm intelligence inspired from the social behaviour and dynamic movement of flocks of birds and schools of the fishes (Tripathi *et al.*, 2007). Basically, PSO algorithm integrates self-experiences of the particles with their social experiences to search for globally optimal solutions (Song, 2014). A proper PSO algorithm must have an ability to combine exploration (i.e., ability to check different regions of the space to find optimum) with exploitation (i.e., ability to converge the search promising regions to locate optimum) in order to provide balance in the algorithm and achieve the effective solution in the search space (Parsopoulos and Vrahatis, 2004, 2007; Zhang and Li, 2010). PSO uses particles to move around in the search space searching for the best solution, and these particles also constitute a population, which is called *swarm* (Parsopoulos and Vrahatis, 2008). In this algorithm, each particle has a memory (i.e., ability to remember) to store its flying experience especially for identifying its best position (Parsopoulos and Vrahatis, 2008). The algorithm aims to move particles gradually towards better areas of the solution space for obtaining optimal solutions. The direction of the movement of each particle is adjusted according to the function of algorithm. The position and velocity of the each particle is adjusted according to the best position visited by itself (i.e., *pbest*) and the best position visited by the entire swarm (i.e., *gbest*) at each step. The PSO algorithm is initialized randomly. In a D-dimensional space position of i^{th} particle is represented with $x_i(t) = (x_{i1}(t), x_{i2}(t), \dots, x_{iD}(t))$, and its velocity is presented with $v_i(t) = (v_{i1}(t), v_{i2}(t), \dots, v_{iD}(t))$, and as well as its best position is shown by $pbest_i = (p_{i1}, p_{i2}, \dots, p_{iD})$.

Steps of basic PSO algorithm are as follows:

1. Initialize swarm (i.e., initialize particles position and velocity randomly);
2. Evaluate each particle position based on the objective (fitness) function;
3. Update particles (*pbest*) (if the current position is better than its previous position);
4. Determine the best particle (*gbest*) (choose the particle with best fitness value as the *gbest* from entire swarm);
5. Update particles velocity (Using Eqn. 1)

$$V_{ij}^{t+1} = wV_{ij}^t + c_1r_1(pbest_i - X_{ij}) + c_2r_2(gbest_i - X_{ij}) \quad (1)$$

6. Move particles to their new positions (Using Eqn. 2)

$$X_{ij}^{t+1} = X_{ij}^t + V_{ij}^{t+1} \quad (2)$$

7. Go to step 2 until stopping criteria is not satisfied;

The definitions of the parameters in Equation (1) are as follows: w is the inertia weight; V_{ij}^t is velocity of the particle i , the position of the particle i is denoted as X_{ij} ; c_1 and c_2 are two acceleration coefficients, which denote for cognitive and social parameters respectively and are set as 2; r_1 and r_2 are two uniformly distributed random numbers that are generated within the range of $[0, 1]$; $pbest_i$ is the best position of the particle; $gbest_i$ is the global best position of the entire swarm; and t is the iteration number. The new position of the particle is updated by using Equation (2); here the new position of the particle is denoted by X_{ij}^{t+1} , X_{ij} is the current position, and V_{ij}^{t+1} is the updated velocity of the particle (Kumar and Minz, 2014).

Problem formulation

Time-cost-quality trade-off problem is a multi-objective optimization problem. In this study, three conflictive objectives are optimized simultaneously. In other words, while time (T) and cost (C) are minimized, quality (Q) is maximized. Equation (3) represents the objective (fitness) function of the multi objective subcontractor selection problem;

$$f \rightarrow \text{Minimization} (f_T, f_C, \frac{1}{f_Q}) \quad (3)$$

The first objective of the trade-off problem is the minimizing total duration of the project. This objective is expressed with the following equation (4);

$$T = \max \sum_{i=1}^m d_{n_i} \quad (4)$$

where T is the total duration of the project, d_{n_i} is the duration of the work package of i on the critical path, m is the total number of work packages in the project, and n_i is the number of subcontractor option for the work package i . Minimizing total cost of the project is the second objective. This objective is calculated by the following equation (5);

$$C = \left\{ \begin{array}{l} \left(\sum_{i=1}^m \sum_{j=1}^{n_i} C_{ij} + IC \times T + \beta [T - D] \right); \quad \text{if } T \geq D \\ \left(\sum_{i=1}^m \sum_{j=1}^{n_i} C_{ij} + IC \times T - I [D - T] \right); \quad \text{if } T \leq D \\ \left(\sum_{i=1}^m \sum_{j=1}^{n_i} C_{ij} + IC \times T \right); \quad \text{if } T = D \end{array} \right. \quad (5)$$

where C is the total cost of the project, C_{ij} is the cost of subcontractor option j for activity i , IC is the daily indirect cost, β is the daily penalty cost, T is the total duration of the project, D is due date of the project and I is the daily incentive cost. The third

objective is the maximizing overall quality of the project. Equation (6) is used to compute this objective;

$$Q = \sum_{i=1}^m w_i \times q_i \quad (6)$$

where Q is the overall quality of the project, w_i is the weight of work package i , and q_i is the quality percentage of the subcontractor option j for activity i .

Development of the Proposed Discrete Particle Swarm Optimization (DPSO) Algorithm

PSO is usually employed to solve continuous problems because of its nature. However, many optimization problems are in discrete type and these problems could only be handled by transforming continuous form of algorithms into discrete form. Time-cost-quality trade-off problem is also a discrete multi-objective optimization problem. Therefore, the PSO algorithm should be developed in a discrete form. The proposed algorithm (DPSO) aims to find most appropriate subcontractors to be worked with for all work packages in a project based on their time-cost-quality performances. In this algorithm, the objective function consists of three objectives, and the algorithm is employed to search for optimal subcontractor sequences, which satisfy the minimum time and cost, and maximum quality objectives. In the DPSO algorithm, the swarm composes of various subcontractor sequences, and a particle corresponds to one of these sequences (see Figure 1).

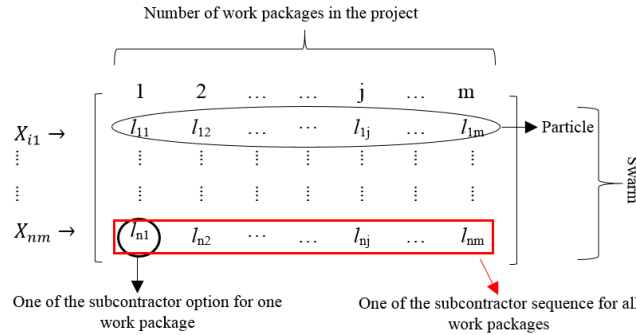


Figure 1: Swarm and particles of representation in the proposed algorithm

The DPSO algorithm was developed as it was explained in the previous sections. In the developed algorithm, the total project duration is determined by using Equation 4. Then, the total cost of the project is calculated using Equation 5. In this equation, the early finish is rewarded with incentive cost; conversely late finish is penalized with penalty cost. The third objective, the overall quality of the project is the computed with Equation 6. Finally, the fitness value of the each particle is evaluated by using Equation 3. Based on the fitness value, the personal best (pbest) for each particle and the global best particle (gbest) in the swarm are identified to guide the swarm in the next iteration. The gbest is determined by using crowded distance (CD) of the each particle that exists in the external archive. The particle with the highest crowded distance is selected as gbest. When archive is full, CD is also used to replace new solutions with existing solutions in the archive. CD is calculated with the following equation:

$$d_{k,k-1} = \sqrt{(f_1(X_k) - f_1(X_{k-1}))^2 + (f_2(X_k) - f_2(X_{k-1}))^2 + (f_3(X_k) - f_3(X_{k-1}))^2} \quad (7)$$

where $d_{k,k-1}$ is the Euclidean distance from the non-dominated solution of X_k from its one of the adjacent neighbour. $f_1(X_k)$, $f_2(X_k)$ and $f_3(X_k)$ are the time, cost and quality values of the fitness function respectively. The described process repeated until the stopping criterion is satisfied.

Case study

In this study the DPSO was developed using the MATLAB software. After developing the DPSO, the data of the trade centre project is used to run the algorithm. This project was built in Samandira, Istanbul, Turkey in 2014 by one of the largest healthcare groups in Turkey. The estimated construction cost was \$7,313,258.07, the total construction area was 2,000 m^2 , the anticipated duration for the project was 500 days, and the contract type was turn-key. In the project, the tasks were grouped into 20 main work packages (i.e., A,...,U). General contractor aimed to perform all these 20 work packages by means of subcontracting. The definitions of 20 work packages are as follows; A: Excavation works, B: Insulation works, C: Core construction works, D: Brick laying, E: Facade works, F: Elevator assembly, G: Plaster works, H: Mechanical works, I: Electrical works, J: Screed works, K: Plasterboard works, L: Epoxy coating, M: Marble coating works, N: Indoor insulation works, O: Ceramic tiles works; P: Door assembling, R: Painting works, S: Furniture and sanitary work, T: Carpet works, and U: Landscaping. Based on the predecessor and successor relationships of these work packages, the network diagram of the trade centre project was constructed (see Figure 2).

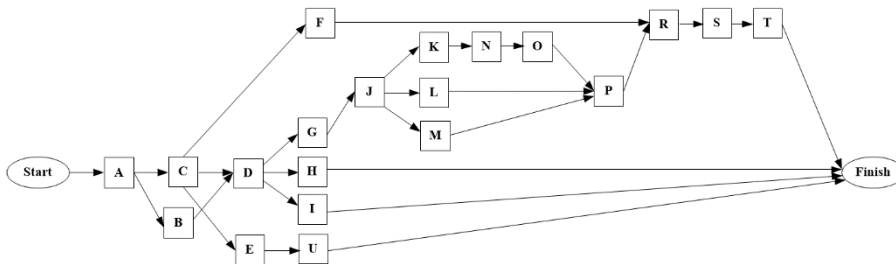


Figure 2: Work packages network diagram

General contractor invited three subcontractor candidates to bid for specified work packages. In other words, three subcontractor options (i.e., Option_1, Option_2 and Option_3) submitted their bids for each work package in the project. In the trade centre project, the duration and bid price values were taken from the bid files of the subcontractors, and the quality of the subcontractors were subjectively evaluated based on the experiences of the general contractors' top managers. Duration, bid price and quality values of the subcontractor options for each work package is presented in Table 1.

Table 1. Subcontractor Options According to the Work packages

Work Packages	Option 1			Option 2			Option 3		
	Duration (days)	Bid Price (\$)	Quality (%)	Duration (days)	Bid Price (\$)	Quality (%)	Duration (days)	Bid Price (\$)	Quality (%)
A	90	1,244,608.29	74	95	1,235,345.62	70	100	1,193,548.39	68%
B	60	170,368.66	79	68	167,050.69	77	72	163,502.30	75%
C	120	1,506,682.03	71	130	1,470,414.75	69	140	1,405,944.70	65%
D	30	85,437.79	87	33	83,041.47	86	35	80,000.00	83%
E	120	420,368.66	90	125	410,092.17	85	130	404,331.80	80%
F	90	255,483.87	85	95	253,824.88	83	100	253,271.89	80%
G	30	108,940.09	72	33	107,695.85	70	36	106,866.36	69%
H	120	584,562.21	77	130	585,345.62	85	135	603,686.64	95%
I	120	479,032.26	82	125	502,350.23	89	130	507,235.02	93%
J	20	123,133.64	70	27	121,152.07	75	32	119,631.34	78%
K	50	182,258.06	88	55	179,907.83	92	60	178,894.01	94%
L	20	80,967.74	74	18	79,354.84	68	15	77,603.69	65%
M	15	56,682.03	77	14	55,668.20	72	13	54654.38	69%
N	15	40,921.66	86	13	42,488.48	91	12	43,778.80	94%
O	20	68,341.01	88	18	70,322.58	91	16	71,428.57	95%
P	15	65,852.53	79	16	63,456.22	75	19	62,811.06	68%
R	45	103,917.05	81	42	105,990.78	77	35	106,958.53	73%
S	20	129,585.25	95	25	128,387.10	90	30	122,488.48	87%
T	20	638,847.93	87	26	617,557.60	82	32	593,732.72	79%
U	60	80,875.58	91	55	83,041.47	85	50	83,870.97	82%

Implementation of the developed multi objective optimization model in the case study

In the studied project, the main objective is to identify the most appropriate combination of subcontractors to be worked with, which offers the minimum project duration and cost, and maximum quality. Since the studied trade centre project consisted of 20 work packages and there are 3 alternative subcontractors for each work package, there are 3.4 billion different subcontractor combinations and each of these combinations will bring about different duration, cost and quality values.

In the first step, the total duration of the trade centre project was calculated by using the critical path method (CPM). For this purpose, the potential paths in the studied project were identified and the durations of these paths were calculated by taking the sum of the durations of the work packages in these paths. Among these paths, the path with the longest duration considered as the total project duration. It should be noted that, the critical path changes in each run due to the change in the combination of subcontractors, so the total project duration was re-calculated in each run.

In the second step, the total cost of the project is calculated based on the due date of the trade centre project. The due date of the trade centre project (D) was given as 500 days and the daily indirect cost was \$230.42. Moreover, the early finish (i.e., $T < D$) is rewarded with incentive cost, conversely late finish (i.e., $T > D$) is penalized with penalty cost in the studied project. The incentive payment was \$345.62 per day, and the penalty cost was \$460.83 per day. The overall quality of the project is evaluated in the third step. In this project, the weight of each work package (w_i) was considered to be equal and set to 1. The optimal control parameters of the DPSO algorithm are taken from the literature review study on multi objective PSO algorithm (Reyes-Sierra and Coello, 2006). The control parameters and boundaries of the objectives are presented in Table 2.

Table 2: Parameters used in the proposed DPSO algorithm

Parameters of the model	Values	Parameters of the model	Values
Swarm size	20	Upper bound of cost	\$6,589,170.51
Archive size	100	Upper bound of quality	85%
w_{min} and w_{max}	(0.9, 1.2)	Lower bound of time	458 days
c_1 and c_2	2	Lower bound of cost	\$6,318,986.18
r_1 and r_2	[0, 1]	Lower bound of quality	77%
Upper bound of time	564 days	Maximum iteration number	500

RESULTS AND DISCUSSION

After running the DPSO algorithm properly, non-dominated solutions were collected in the external achieve. Since the discussed problem is multi objective optimization problem, it is usual to have more than one optimal solution. This research aims to propose a set of optimal solutions to the decision makers from which they can select the subcontractor combination, which fulfils their targets. Among the obtained solutions, nine different Pareto-optimal solutions are presented in Table 3.

Table 3: Nine Pareto optimal subcontractor sequences for each work packages

Solution	Optimal subcontractor combinations	Project performance		
		Time (day)	Cost (\$)	Quality (%)
1	1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-3-1-1-1	465	6,524,953.92	81.25
2	3-1-1-1-1-1-3-1-1-1-1-1-1-1-1-3-1-1-1	475	6,498,758.06	81.85
3	3-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-3-1-1-1	475	6,479,654.38	80.95
4	3-1-3-1-1-1-3-1-1-1-1-3-3-3-1-3-1-1-1	488	6,409,447.00	81.90
5	3-1-3-1-1-1-3-1-1-1-1-3-2-3-1-3-1-1-1	489	6,408,732.72	81.75
6	3-3-3-1-1-1-2-1-1-1-1-3-3-3-1-3-1-3-1	500	6,346,036.87	80.80
7	3-3-3-1-3-1-2-1-1-1-1-1-3-2-3-1-3-1-2-1	495	6,349,654.38	80.30
8	3-3-3-1-2-1-3-1-1-2-1-3-3-3-1-3-1-1-1	493	6,392,834.10	81.65
9	3-1-3-1-1-1-1-3-1-1-1-1-1-3-3-3-1-3-1-3-1	500	6,371,244.24	81.50

According the results displayed in Table 3, if the primary target is to minimize the total duration of the project (i.e., Time: 465 days), then the decision maker should select the first solution in Table 4. To achieve the minimum duration, the general contractor should employ the corresponding subcontractor plan (i.e., subcontracting sequence A:1 , B:1, C:1, D:1; E:1; F:1; G:1; H:1; I:1; J:1; K:1; L:1; M:1; N:1; O:1; P:1; R:3; S:1; T:1; U:1) for 20 work packages. Also, this row represents the best compromise solution (i.e., Time: 465, Cost: \$6,524,953.92, Quality: 81.25%), which satisfies all objectives simultaneously. If the decision maker attaches more importance to minimize the total cost (i.e., Cost: \$6,346,036.87), then the subcontractor combination indicated in the sixth row (i.e., subcontracting sequence A:3 , B:3, C:3, D:1; E:1; F:1; G:1; H:2; I:1; J:1; K:1; L:1; M:3; N:3; O:3; P:1; R:3; S:1; T:3; U:1) should be selected to satisfy this target. If the quality (i.e., 81.85%) is the primary target of the project, decision maker should select the second row (with subcontracting plan A:3 , B:1, C:1, D:1; E:1; F:1; G:1; H:3; I:1; J:1; K:1; L:1; M:1; N:1; O:1; P:1; R:3; S:1; T:1; U:1) to achieve this target. In the same manner, the decision maker can make any selection from the given Pareto optimal solutions to satisfy the project's primary targets. The estimated cost of trade centre was \$7,313,258.07 and the anticipated duration was 500 days. Therefore, the trade centre project could be easily executed with lower cost, less duration and high quality by selecting one of the proposed subcontracting plans for employing in the project.

CONCLUSIONS

Selecting the right subcontractor for the right job is a very important decision making problem in the construction industry. This study generated a discrete particle swarm optimization algorithm (DPSO), which aims to assist general contractors to select the most appropriate subcontractors that will carry out different work packages in a construction project considering the trade-off between time, cost and quality. The main contribution of this study is to consider the subcontractor selection problem as a multi objective optimization problem. The real data of a trade centre project was used to run the developed DPSO algorithm. Pareto-optimal solutions indicated that the developed algorithm is quite satisfactory. The developed DPSO is of benefit to general contractors as it allows them to select the most appropriate subcontractor combination among a set of optimal solutions considering their unique project targets.

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VALIDATION OF A MODEL FOR ASSESSING ALLIANCE TEAM INTEGRATION

Khairil Izam Ibrahim¹, Seosamh B. Costello² and Suzanne Wilkinson³

¹*Faculty of Civil Engineering, Universiti Teknologi MARA, Malaysia*

^{2 and 3}*Department of Civil and Environmental Engineering, The University of Auckland, New Zealand*

An approach towards fostering continuous team integration practice in project alliancing is essential for stimulating breakthrough outcomes. However, until recently there was no standard or systematic approach for measuring the integration practice over the life cycle of alliance projects. This paper presents such an assessment model, the Alliance Team Integration Performance Index (ATIPI), to measure the current state of the team integration performance. With the aid of a panel of alliance experts, seven dominant key indicators (KIs) with their respective quantitative measures (QMs) and performance scales were identified for inclusion in the ATIPI. As the focus of this paper, a means of examining the validity of the model is demonstrated through the use of the face validity method with a panel of experts in the field of project alliancing. The results indicate that the proposed assessment model was found to be applicable in objectively measuring team integration performance. Based on the lessons learned from the expert's interviews, the reliability of the model could be further enhanced in order to enable owner and non-owner participants to gain an insight into the team integration performance consistently and objectively.

Keywords: alliance, team integration, validation, New Zealand.

INTRODUCTION

Project alliancing is regarded as a potential panacea for enhancing integration efforts in the construction industry (Love *et al.*, 2010; Chen *et al.*, 2012). However, in spite of the fact that a high level of integration is a widely understood feature of the alliance model, the ability to sustain and consistently drive the integration practice to achieve the desired outcomes is of on-going concern (Laan *et al.*, 2011). One possible explanation for the on-going concern is that project teams are frequently isolated in environments where adversarial cultures and attitudes still exist (Laan *et al.*, 2011). In addition, some individuals may experience culture shock in the new environment, and coping within a new challenging project environment may contribute to the difficulty to integrate proactively and to move away from the traditional adversarial approach (Reed and Loosemore, 2012). This phenomenon potentially occurs because the principle of the alliance model is yet to mature for some industrial players (Yeung *et al.*, 2007) and the need for alliance team members to possess different attributes than those involved in business-as-usual (BAU) in order to strengthen the sources of integrated practice (Ibrahim *et al.*, 2013).

Against this background, the need for consistent integration practice over the lifecycle of an alliance project, mentioned by previous scholars, assumes a special significance to enhance the continuity of the integration within the alliance teams. For countries

¹ cche365@aucklanduni.ac.nz

such as Finland and New Zealand, where the level of maturity in the alliance model is now gathering pace in the industry, it is critical that a means of understanding team integration practice, more importantly, how to drive continuous and consistent performance in this area, is vital to its continued success. Although prior research on team integration emphasized the importance of measuring integration practice, the findings only focused on subjective assessment rather than empirical evidence. For example, Baiden *et al.* (2006) focused on assessing the extent of team integration in Design and Build (DB) and construction management procurement approaches. They concluded that either an integrated team is necessary, or the industry must overcome the existing adversarial culture, for project performance to be improved. Some other researchers, Aapaoja *et al.* (2013) by contrast, examined the level of team integration practice in building projects procured by the integrated project delivery (IPD) method. They emphasized that due to the integrated nature embedded in the IPD method, projects can be successful although some of the integration characteristics are not fully achieved.

Despite the aforementioned research, the issue of assessing team integration practice objectively, remains elusive. Although these studies made significant progress in assessing the integration practice, they mainly attempt to reveal evidence of the integration practice using a subjective assessment (e.g. fully integrated, partly integrated) rather than trying to assess the practice objectively over time. As a result, it is very difficult to quantify an actual measure for team integration based on these findings. Recognising that there are no standard or accepted methods in the industry to assess the alliance team integration performance, Ibrahim *et al.* (2013) have developed an assessment model, the Alliance Team Integration Performance Index (ATIPi) for assessing alliance team integration performance. However, whether the assessment tool is valid and performs its intended function for the use of industry, should be determined through a process of validation. The validation process, in research in the construction domain, is a fundamental element of the process of scholarly endeavour (Lucko and Rojas, 2010).

The purpose of this paper is to present the validation process of the ATIPi model through an interview with thirteen alliance practitioners, based on six validation aspects. Consequently, the subsequent sections of the paper briefly provide an overview of the development of the ATIPi model. Further details on the research and development of the ATIPi model can be found in Ibrahim *et al.* (2013, 2014, 2015). Then, the research method is introduced and findings of the validation interview sessions are analysed. Finally, the discussions are presented, followed by the conclusions.

ATIPi MODEL STRUCTURE

As summarized in Figure 1, the development framework for the ATIPi model consists of three phases including Key Indicator (KI) identification, Quantitative Measure (QM) identification, and the range of scales for five performance levels.

Phase 1: The most significant Key indicators, signifying their dominant influence

In Phase 1, four rounds of Delphi questionnaire survey were undertaken with a panel of 17 experienced alliance practitioners to identify and weight the most significant KIs to measure the success of alliance team integration in road construction projects. Over the course of the Delphi survey, the seven most significant KIs were identified, as follows: (1) team leadership; (2) trust and respect; (3) a single team focus on project

objectives and Key Result Areas (KRAs); (4) collective understanding; (5) commitment from project alliance board; (6) creation of single and co-located alliance team; and (7) free flow communication (see Ibrahim *et al.* (2013) for a detailed discussion). The ATIPI was then developed based on the preceding KIs and their weightings, as shown for Phase 1 in Figure 1.

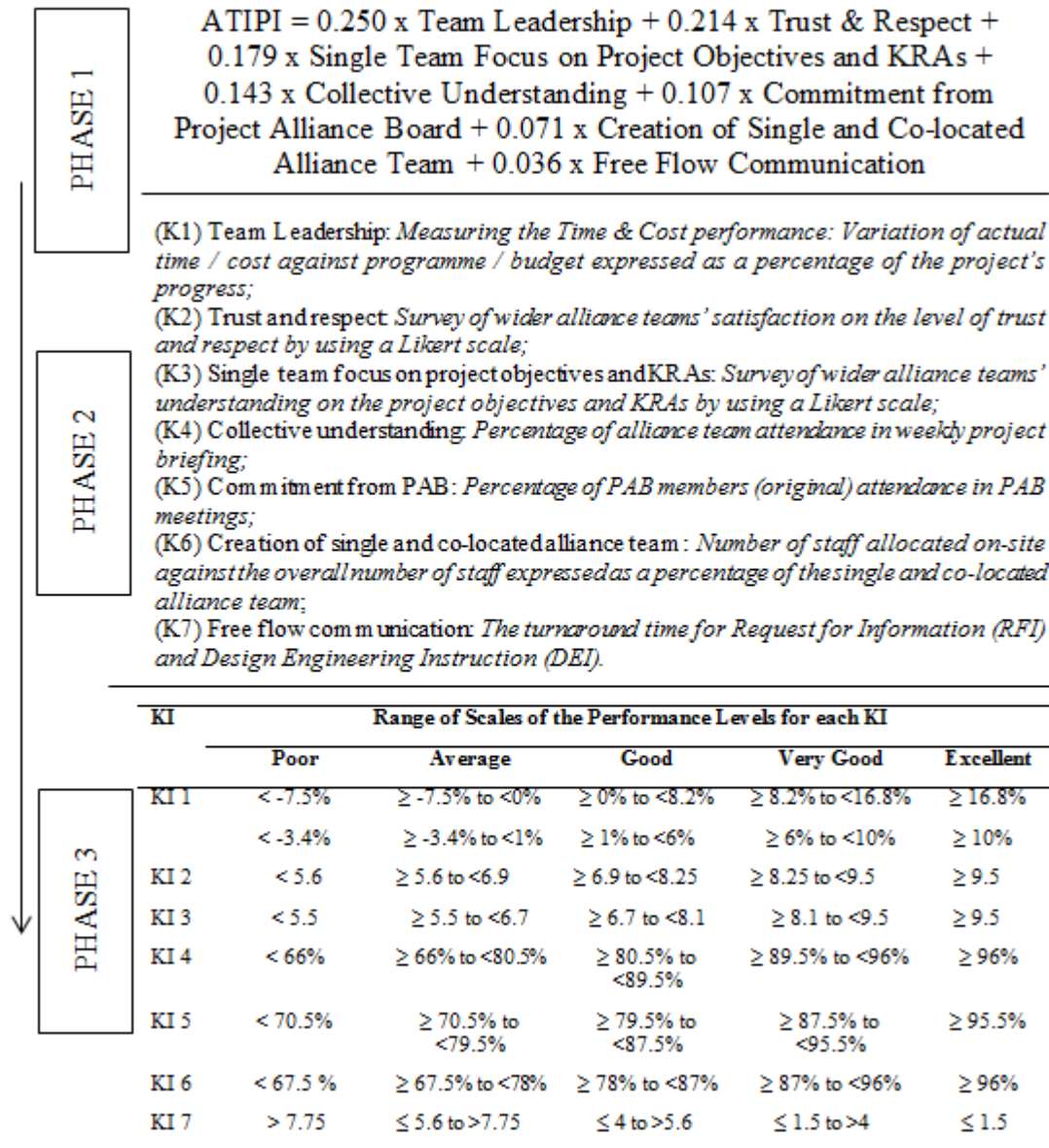


Figure 1: Development Phases of the ATIPI Model

Phase 2: The suitable Quantitative Measures (QMs) for each of the KIs, to promote objective assessment over time

Once the significant KIs for alliance project teams were identified from Phase 1, the next level of development of the model, Phase 2, involved identification of appropriate measures, in order to promote objective assessment over time for those seven KIs. Consequently, in Phase 2, a semi-structured interview with five experienced alliance practitioners was conducted to identify suitable, practical and objective measures to help evaluate the seven selected weighted KIs. As a result, a

total of 29 quantitative measures (QMs) were proposed and recommended. Then, two rounds of Delphi questionnaire survey were undertaken with the same 17 Delphi experts to identify the most appropriate QMs for each KI based on their levels of importance, measurability and obtainability (See Ibrahim *et al.* (2014)).

Phase 3: The performance level boundaries for each KI, to reduce the subjectivity of assessment and promote consistency

The next level of development of the model, Phase 3, involved the development of an associated range of scales for each KI to indicate the boundaries of the different performance levels in the ATIPI. The performance levels establish the points at which alliance teams have demonstrated sufficient integration practice to be regarded as performing at a particular achievement level. Accordingly, Phase 3 of the model development included a systematic procedure based on a questionnaire survey and fuzzy set theory, namely the modified horizontal approach with bisector error method, to establish a range of scales for each QM within five levels of performance. The five performance levels designated are excellent, very good, good, average and poor. Although the ATIPI has been verified to be functioning to perform its intended purpose (see Ibrahim *et al.* (2015)), the availability of a computerized rather than manual assessment tool is vital to encourage its uptake in the industry.

The ATIPI excel spreadsheet was made available for download as open software via an established free file hosting website at the following link: http://www.mediafire.com/view/3p1jbkr76ctx8e0/ATIPI_Demo_Final_AiC.xlsx. The tool is still a prototype model and currently only allows entry of one set of assessment data. The following section describes the validation of the model to measure the integration practice in alliance projects.

VALIDATION OF THE ATIPI MODEL

Research in performance measurement, in particular in the construction domain, has gained increasing attention over the past few decades. Two research studies, in particular, are highlighted here, namely Chow and Ng (2007) who developed the consultants performance evaluation (CPE) model using a gap analysis technique and Ng and Skitmore (2014) who developed the subcontractor appraisal performance using a balanced scorecard. It is worth noting that although these three studies each use different techniques to develop the performance model, they all use the same type of validation, that is face validity, to validate their respective models. Face validity is based on subjective judgement, is non-statistical in nature, and requires the opinion of non-researchers regarding the validity of a study (Leedy and Ormrod, 2001). For example, a specific model can be said to have face validity if the experts in the respective field analyse the model and its output represents, to a high degree, what happens in reality. In a domain such as construction management and engineering, collaboration with appropriate representatives from private and public sectors is vital to secure the face validity of the study (Lucko and Rojas, 2010).

RESEARCH METHOD

In this study, the face validity approach, using a structured interview technique, was adopted to validate the ATIPI. The ATIPI model was validated by a total of 13 alliance practitioners including five alliance experts used in the Delphi study (referred to as Internal Experts) and another eight experienced alliance practitioners (referred to as External Experts) who had not previously participated in the development of the ATIPI, as shown in Table 1.

Table 1: Profile of alliance practitioners who participated in the model validation process

Experts	Position	Organization
1*	Design Manager	Consultant
2*	General Manager	Consultant
3*	Project Controls Manager	Consultant
4*	Chief Advisor	Client
5*	Alliance Manager	Contractor
6	Communication Manager	Client
7	Design Manager	Consultant
8	Quality Assurance and Systems Manager	Contractor
9	Project Director	Consultant
10	Sub Alliance Manager	Contractor
11	Consents Assurance and Key Results Manager	Client
12	Project Controls Manager	Contractor
13	Owner Interface Manager	Client

Note: * Internal Experts who had participated in developing the ATIPI

The eight external experts were selected based on two criteria: (1) Pertinent / Relevant and verifiable previous experience in alliancing projects in New Zealand; and (2) Having recent/on-going and direct involvement on a Project Alliance Board (PAB) or Alliance Management Team (AMT). O'Leary (1987) emphasised that using internal experts in the validation process will ensure that the model has captured their expertise and that the experts have thought about what it takes to structure the model. In contrast, using external experts offers advantages such as the potential for another point of view and a test of unstated assumptions in the model. Moreover, Yeung *et al.* (2009) argued that having independent or different validators will ensure no biased validation results exist. Thus, incorporating the views of different validators will ensure an equitable and reliable validation process. Although previous scholars like Chow and Ng (2007) and Yeung *et al.* (2009) used 8 and 7 validators, respectively, for their model validation, this study used 13 validators to help ensure a rigorous validation. In addition, having a balance of organisations represented among the experts; consultant (38.4%), contractor (30.8%) and client (30.8%), will help prevent bias. Moreover, the 13 experts have more than 6 years of experience on average, at management level specifically in alliancing contracting and more than 15 years in collaborative arrangements, which indicates they are highly qualified and capable to carry out the validation.

Results and Analysis

A qualitative methodology by using structured face to face interviews has been used as the research approach for this validation study. Initially, the validators were briefed on the aim and objectives of the study and then guided through the overall integration of KIs, QMs and the range of scales for performance levels for inclusion into the development of the ATIPI model. Validators were then invited to provide an evaluation of the ATIPI model through a scoring sheet. In total, six aspects were validated including; 1) *Degree of appropriateness*: The relevancy of the KIs, QMs and ranges of scales for Performance Levels included in the ATIPI; 2) *Degree of objectivity*: The degree of objectivity in the assessment; 3) *Degree of replicability*: The ability of the tool to be replicated or used on other alliance projects; 4) *Degree of practicality*: The level of practicality of the tool to be used in actual alliance projects; 5) *Overall reliability*: The ability of the ATIPI to consistently perform its intended

function; and 6) *Overall suitability to be adopted as an assessment tool*: The suitability of the ATIPI to be adopted as an assessment tool to measure the team integration performance of alliance teams.

They were asked to provide a score on a validation scoring sheet according to a 5-point Likert scale (1 representing ‘not at all satisfied’ to 5 representing ‘extremely satisfied’) to signify their extent of satisfaction on each of the validation aspects. The results of validation of the ATIPI model are summarized in Table 2, in which the rating of each expert and mean ratings of each validation aspect are shown.

Table 2: Validation results based on responses of 16 alliance validators

Validation Aspect	Alliance Validators													Mean rating
	1*	2*	3*	4*	5*	6	7	8	9	10	11	12	13	
Degree of Appropriateness	3	4	4	3.5	5	4	4.5	4	3	3.5	4	4	4	3.88
Degree of Objectivity	4	4	4	3.5	4	5	3.5	5	4	4	4	3	4	4.00
Degree of Replicability	4	5	4	5	4	4	5	5	4	5	4	4	4	4.38
Degree of Practicality	4	4	4	4	5	4	3	5	4	4	4	3	4	4.00
Overall Reliability	3	4	4	5	3	4	4.5	5	4	3.5	4	3	3	3.85
Overall Suitability	3	3	4	4	5	3	4	5	3	4	4	3	4	3.77

Note: 1= Not at all satisfied and 5=extremely satisfied

* Internal Experts who had participated in developing the ATIPI

The validation results show that the *Degree of Appropriateness* received a mean rating of 3.88 indicating the extent of experts’ satisfaction on the relevancy of the characteristics of the ATIPI is ‘satisfied towards very satisfied’. The second validation aspect in terms of *Degree of Objectivity* of the ATIPI received a response ‘very satisfied’ with a mean rating of 4.00. The majority of the experts believed that the ATIPI is an objective assessment tool to measure the alliance team integration, as the majority of the QMs are quantitative in nature and characteristic, and, hence, influence the objectiveness of the tool. Next is the third validation aspect, the *Degree of Replicability* which received a ‘very satisfied to extremely satisfied’ (mean rating of 4.38) response among the experts on the ability of the tool to be replicated on other alliance projects. The fourth validation aspect, *Degree of Practicality*, received a mean rating of 4.00, resulting in a ‘very satisfied’ response among the experts. *Overall Reliability* is the fifth validation aspect and received a satisfaction response of ‘satisfied towards very satisfied’ with a mean rating of 3.85. Again, due to the characteristics of the ATIPI, most of the experts believe the tool has the ability to consistently perform its intended function, although some experts believe it needs to be tested and piloted in practice on a numbers of alliance projects and over the lifecycle of the projects to be absolutely sure of its reliability. The final validation aspect is the *Overall Suitability*, which received a mean rating of 3.77, thus indicating a response of ‘satisfied towards very satisfied’.

Overall, it is worth noting that high ratings (mean rating ≥ 4.0) were achieved for 'degree of objectivity', 'degree of replicability' and 'overall practicality' and a mean rating of greater than 3.7 and less than 4.0 was achieved for "the degree of appropriateness, degree of reliability and overall suitability". It should be highlighted that, in accordance with studies such as Chow and Ng. (2007) and Yeung et al. (2009), mean ratings greater than 3.5 are adequate to warrant validation of a model. To summarize, the validation results have confirmed that the ATIPI model could assist in assessing the alliance team integration performance in road infrastructure projects. In addition, any variability in responses between the internal and external experts did not affect the validation aspects of the ATIPI, as the responses from both categories of experts were consistent based on mean responses.

DISCUSSION

The findings of the research revealed that the ATIPI model could potentially assist in assessing the alliance team integration performance in road infrastructure projects. However, it is worth highlighting that every performance model has its own limitations which can be exacerbated, unless methodological considerations are carefully selected and applied under suitable settings (Yang *et al.*, 2010). Some issues were highlighted and possible improvements were suggested during the validation in order to enhance the applicability of the model to real alliance projects. Notably, during the validation process, the strength of the model was called into question specifically upon the assessment of QMs for the respective KIs. In particular, concerns related to how a single QM could directly measure what can be a complicated KI. For example, as critiqued by some of the experts, how cost and schedule performance could fully represent the KI of team leadership, which is more abstract and hard to quantify. Grint (2005) stated that the basic definition of leadership has yet to be agreed, *let alone* whether it can be measured, despite vast research into application of leadership skills to project teams (Walker, 2015). Although the QM for team leadership was questioned in the validation, some research studies in the construction domain indicate that there is a relationship between cost and schedule performance and leadership. Lendrum (2011) stated that cost and time improvement are seen as value propositions underpinning alliancing that linked directly with leadership styles and characteristics. In fact, Yang *et al.* (2011) found that there is an interrelationship between shared leadership and project success due to project complexity. They emphasized that projects were more likely to be successful when they experienced high levels of shared leadership. The complexity to quantify such an input for the QM, has lead the experts to choose a measure based on ease of measurement and obtainability to address those indicators (Ibrahim *et al.*, 2014). Overall, the validation experts believe that while the recommended QMs covered the range of possibilities of appropriate QMs, the final selection may have been influenced by the experience of the alliance experts in measuring such an indicator in their alliance projects.

A key consideration in developing the ATIPI was to ensure that it was a practical and useable model. To that end it was decided to include only one QM for each KI. However, as proposed during the validation, this is a potential limitation, in that certain aspects of the KI may not be captured effectively with just one QM. The issue on the capacity to have more than one QM for each KI is desirable based on comments by the experts, as it may provide greater coverage of the influencing factors for the KI. For example, the establishment of a lead and lag QM, with a combination of quantitative and qualitative measures, if applicable, for each KI would help to enhance the characteristics of the assessment tool. Yeung *et al.* (2013) described that ability to incorporate leading and lagging performance indicators will provide

early warnings, identify possible problems that could lead to opportunity for organizational change.

In addition, demonstrating the application of the model in real life was suggested to ensure the applicability of the model. Experts also suggested that the frequency of the assessment should be on a quarterly basis, rather than monthly, to allow time for variation in the data and, hence, provide sufficient time for managerial teams to measure, analyse and respond to the performance. A longitudinal study to assess the alliance integration performance in different stages of alliance projects is proposed. Results from these studies will assist with the development of a more complete and accurate team integration performance database. In addition, factors that might affect the integration performance identified during the demonstration of the model (e.g. complexity of the project, size and characteristics of the alliance teams), could also be addressed in a longitudinal study. Such studies would help to refine the measurement indicators or reveal other key indicators which can impact on team integration and isolate the lessons learned and best practices from different types of alliances. Such findings could be integrated in the ATIPI as guidance for continuous improvement.

While the development of the ATIPI into an online model is beyond the scope of this study, the experts recommended that further enhancement of the model's functionality with more adaptive capabilities and the establishment of an integrated online-based platform is undertaken. Thus, administration of the domain knowledge of the model can be enhanced and the assessment and monitoring process will be openly accessible to authorized alliance managerial teams.

Comparison to related studies on integrated index model in construction research

The establishment of the ATIPI model in this study presents an opportunity for comparison with for other types of index model. For example, Cheung *et al.* (2003) developed the system for monitoring the status of partnering in Hong Kong through the use of an index, based on the incorporation of an established partnering measure. Yeung *et al.* (2007) focused on measuring the overall performance of a partnering project in Hong Kong, by establishing a specific key performance indicator (KPI) through the use of Delphi method. In contrast, Xia and Chan (2012) focused on assessing the degrees of project complexity in China by identifying the complexity measures for building projects. Overall, although aforementioned studies were based on the same concept, they are all different in terms of their focus, scope, methodology as well as the validation process, and hence result in different outcomes.

The validation of the ATIPI confirm that the model provide an automated way of assessing in terms of collecting, retrieving and presenting graphically empirical data (i.e. objective results) to assist in managing the integration practice consistently and continuously. Such assessments could lead to recognition of pattern variations, which in turn lead to identification of which indicators are dominant to their integration practice, thereby focusing alliance managerial team attention and reach much faster on those that will have the greatest impact in terms of its strengths and weaknesses and plan ahead for improvement. Waiting until the end of the project for analysis and reports is no longer a practical management strategy in delivering complex projects. It is worth noting that the ATIPI is not a direct measure of successful team performance, as a whole. Rather, it is a proactive management approach focused on measuring team integration performance consistently and objectively.

Overall, the ATIPI model provides an alternative methodology to the existing approach outlined in the literature for assessing the team integration, which is

subjective and limited to non-collaborative arrangements, with little focus on making the assessment objective and systematic.

CONCLUSIONS

The ATPI aims to be a platform for teams to reflect and discuss how their team relates to each of the indicators and the impact of this on their integration practice. In addition, the ATIPI captures key insights into team performance and, hence, provides a point of reference to drive continuous improvement.

This paper presented the validation of the ATIPI. The findings confirm that the ATIPI is a simple and user-friendly assessment tool that enables alliance teams to self-diagnose and better understand the current state of their team integration performance over the course of the project. This is further supported by the positive validation feedback given by a selection of alliance experts, although some improvements based on the expert's interviews could be incorporated to further improve certain features of the model, thereby facilitating its application in the alliancing industry. In addition, the validation of the ATIPI could possibly be further expanded in future by testing its application on different project stages on a number of on-going alliance projects, not only in New Zealand but in other countries. Such studies would help to enhance the model in terms of integrating the best practices from different types of alliances, and hence, improve the project outcomes.

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PARETO ORIENTED OPTIMIZATION OF DISCRETE TIME-COST TRADE-OFF PROBLEM USING PARTICLE SWARM OPTIMIZATION

Saman Aminbakhsh¹ and Rifat Sonmez

¹*Civil Engineering-Construction Engineering and Management Department, Middle East Technical University, Ankara, Turkey*

In project scheduling, it is feasible to reduce the duration of a project by allocating additional resources to its activities. However, crashing the project schedule will impose additional costs. Numerous research has focused on optimizing the trade-off between time and cost to achieve a set of non-dominated solutions. However, the majority of the research on time-cost trade-off problem developed methods for relatively simple problems including up to eighteen activities, which are not representing the complexity of real-life construction projects. In this work a Particle Swarm Optimization (PSO) technique is presented for Pareto oriented optimization of the complex discrete time-cost trade-off problems. The proposed PSO engages novel principles for representation and position-updating of the particles. The performance of the PSO is compared to the existing methods using a well-known 18-activity benchmark problem. A 63-activity problem is also included in computational experiments to validate the efficiency and effectiveness of the proposed PSO for a more complex problem. The results indicate that the proposed method provides a powerful alternative for the Pareto front optimization of DTCTPs.

Keywords: Pareto front, particle swarm optimization, project scheduling, time-cost trade-off problem.

INTRODUCTION

Opposed to other industries, transient nature of the construction projects imposes heavy burden on decision makers regarding unequivocal optimal devotions of time, cost, and resources (Hegazy 1999). Either at the planning stage or in case the project is running behind the scheduled plan, the contractor and the client, as the main parties to a construction project normally strive to complete the project within shorter durations at the minimum cost possible. However, crashing the project schedule imposes additional costs and might be profitable up to a certain limit (Zheng *et al.* 2005). Accordingly, analyses of the trade-off between time and cost in view of obtaining a set of non-dominated solutions is a significant aspect of the construction management. Classical network analyses like critical path method (CPM), in essence, merely incorporate the cost and project deadline aspects (Aminbakhsh 2013). Such methods attempt to minimize the project duration regardless of the availability of resources (both money and physical resources). Any reduction in project duration is facilitated by crashing the project schedule. Decision makers speed up the project by using additional labour and machinery or by adopting alternative construction techniques (Hegazy 1999). The best combination of crashing alternatives is facilitated

¹ saman.aminbakhsh@metu.edu.tr

by optimizing the balance between the direct and indirect costs of a project. The trade-off between time and cost of a project is known as the time-cost trade-off problem (TCTP) (Feng *et al.* 1997), discrete version of which (DTCTP) considers discrete sets of time-cost options for the activities. Such a concern is imperative to TCT analyses as real-life projects comprise resources of discrete units. In Pareto oriented optimization of DTCTPs, non-dominated optimal total costs are mapped to feasible completion times to generate Pareto fronts of the problems.

Commercial scheduling software packages, in general, do not bear any strategies for the DTCTP. The methods proposed for the DTCTP can be classified into three categories: exact methods, heuristics, and meta-heuristics. Exact methods based on mixed integer programming (De *et al.* 1995; Szmerekovsky and Venkateshan 2012), branch and bound (Demeulemeester *et al.* 1998; Vanhoucke 2005), and Benders decomposition (Hazır *et al.* 2010) can solve small scale problems. Few research work has focused on the development of heuristic methods for the time-cost trade-off problem (Prager 1963, Siemens 1971; Goyal 1975, Moselhi 1993). The most recent heuristic method for DTCTP is implemented by Hegazy (1999) which is rooted upon Siemens's (1971) method. In recent years the significant developments in meta-heuristic algorithms has enabled researchers to shift focus from heuristics to meta-heuristic methods for DTCTP. Genetic algorithms (Feng *et al.* 1997; Hegazy 1999; Zheng *et al.* 2005; Kandil and El-Rayes 2006; Eshtehardian *et al.* 2008; Fallah-Mehdipour *et al.* 2012; Sonmez and Bettemir 2012), ant colony optimization (Ng and Zhang 2008; Xiong and Kuang 2008; Afshar *et al.* 2009), particle swarm optimization (Yang 2007; Zhang and Xing 2010; Fallah-Mehdipour *et al.* 2012), shuffled frog leaping (Elbeltagi *et al.* 2007), and Electimize (Abdel-Raheem and Khalafallah 2011) are among the meta-heuristics implemented for the TCTP. Despite Pareto front optimization is reckoned to be the ultimate resolution of TCT analyses (e.g. Zheng *et al.* 2005; Yang 2007; Eshtehardian *et al.* 2008), relatively scarce devotions are made toward this end. The majority of the existing research in their computational experiments has focused on solving relatively simple problems that include up to only 18 activities with 5.9E09 number of possible resource utilization options. The main objective of this study is to present an efficient PSO model incorporating novel principles for binary representation and position-updating of the particles which is capable of exerting the Pareto front optimization for complex DTCTP. The practiced complex instance includes 63 activities with 1.37E42 number of possible combinations of time-cost alternatives.

PARETO FRONT AND OPTIMIZATION MODEL

Pareto front optimization is a multi-objective decision making problem that any of its objectives might reach their optimal amounts at miscellaneous points called the Pareto Front. Obtaining the Pareto front for TCT problem, in essence, engages concurrent optimization of two classical TCT extensions, viz., the budget and the deadline problems. The bi-criterion TCT optimization problem can be formulated as follows:

$$(1) \quad \text{Minimize } y \equiv (D_i, C_i)$$

$$(2) \quad D_i = \max \left[\sum_{j=1}^S \sum_{k=1}^m d_{jk}^{(t)} x_{jk}^{(t)} \right]$$

$$(3) \quad C_i = \sum_{j=1}^S \sum_{k=1}^m dc_{jk}^{(t)} x_{jk}^{(t)} + D_i \times ic$$

where D_i and C_i denote total duration and total cost of i th solution, respectively; d_{jk} and dc_{jk} represent duration and direct cost of the k th options of the j th activity, respectively; and ic denotes the daily indirect cost.

PROPOSED PARTICLE SWARM OPTIMIZATION METHOD

The PSO method, imitating bird flocks that forage and fly in unison, was first introduced by Kennedy and Eberhart (Eberhart and Kennedy 1995; Kennedy and Eberhart 1995) who later developed a binary paradigm of their model for problems incorporating discrete objective functions (Kennedy and Eberhart 1997). In the proposed PSO method, each particle represents a solution in a S -dimensional solution space. The position and velocity of i th particle for the k th option of the j th activity, in the time step t is represented by $x_{ijk}^{(t)}$ and $v_{ijk}^{(t)}$, respectively. Moreover, the proposed PSO involves binary values, that is, each particle i , for its j th activity can only have a single k set to one, with all the remaining components of the j th activity holding zero (viz., for a solution generated by PSO, at time-step t : $\sum_{k=1}^{m(j)} x_{jk}^{(t)} = 1$). An external archive, O has been dedicated to the PSO model, so as to store all the non-dominated solutions found by this algorithm. A controller, Eq. (4), is implemented to carry out judgments regarding particles' qualification to enter the external archive (Aminbakhsh 2013). For any decision vector x , this controller engages the following criteria with respect to the measured D_x and C_x :

$$(4) \quad \left\{ \begin{array}{ll} \text{Accept} & \text{if } D_x \neq D_y \\ & \text{or } \begin{cases} D_x = D_y \\ C_x \leq C_y \end{cases} \\ \text{Reject} & \text{otherwise} \end{array} \right.$$

where; D_y and C_y , respectively, represent duration and cost of particle y – an existing solution stored in the archive O . The quality of the solutions are compared to determine the personal best positions, P_i 's, experienced by any of the particles.

According to Eq. (5), for decision vectors u and v :

$$(5) \quad u > v \quad \text{if} \quad \begin{cases} C_u < C_v & \text{or} \\ C_u = C_v & \text{and } D_u < D_v \end{cases}$$

Since all the archived solutions are non-dominated with equal qualities, in order to provide dynamic exploitation of the archived solutions, PSO utilizes an effective multi-objective approach in measuring global best positions, P_g 's, of the particles.

Throughout each iteration, PSO randomly selects non-dominated solutions as the P_g 's of the particles. Particles fly to their new positions using the velocity vector given in Eq. (6),

$$(6) \quad v_{ijk}^{(t+1)} = w^{(t)} v_{ijk}^{(t)} + c_1 r_1 (P_{ijk}^{(t)} - x_{ijk}^{(t)}) + c_2 r_2 (P_{gjk}^{(t)} - x_{ijk}^{(t)})$$

where; w is the inertia weight; r_1 and r_2 are uniformly distributed random vectors between $[0,1]$; and the constants c_1 and c_2 are the cognitive and social parameters, respectively.

In the proposed PSO, velocity vectors are transformed into probabilities (Aminbakhsh 2013) and are normalized to the range $[0,1]$ using a logistic transformation function given in Eq. (7). Then, subject to the probabilistic condition specified in Eq. (8), each particle moves to a new position in the solution space.

$$(7) \quad sig(v_{ijk}^{(t)}) = \frac{1}{1 + \exp(-v_{ijk}^{(t)})}$$

$$(8) \quad x_{ijk}^{(t+1)} = \begin{cases} 1 & \text{if } sig(v_{ijk}^{(t+1)}) = \max\{sig(v_{ijk}^{(t+1)})\} \\ 0 & \text{otherwise} \end{cases}$$

The optimization process is reiterated until the stipulated number of iterations is reached. Subsequently, PSO returns the ultimate archived non-dominated solutions.

TEST INSTANCES

For performance evaluation of the proposed PSO method, a small-scale problem, as well as a more complex medium scale instance is implemented.

1) Small-scale test instance

The first test problem involves the 18-activity network, details of which can be derived from Feng *et al.* (1997) incorporating the time-cost alternatives defined in Hegazy (1999). The majority of the previous research (Zheng *et al.* 2005; Ng and Zhang 2008; Afshar *et al.* 2009; Zhang and Ng 2012) used this problem to evaluate the performances of the proposed multi-objective meta-heuristics. This problem with a total of 5.9E09 possible schedules is examined with a daily indirect cost of \$1,500.

2) Medium-scale test instance

In the course of the analyses, Sonmez and Bettemir's (2012) hypothetical 63-activity problem is used as the second test instance. This medium scale complex problem consists of 1.37E42 different time-cost alternatives and a daily indirect cost of \$2,300.

COMPUTATIONAL EXPERIMENTS AND COMPARISONS

Computational experiments were conducted to evaluate the performance of the proposed PSO method for Pareto front optimization of DTCTP using benchmark instances. The proposed algorithm was coded in C++ and compiled in Visual Studio 2013. All of the tests were carried out on a computer with an Intel Core i7-3.40 GHz CPU. Pilot experiments were conducted to determine an adequate set of parameter values for the PSO algorithm. The pilot experiments revealed that the set of parameters that are summarized in Table 1 provides an adequate combination for the PSO. 200,000 and 1,000,000 schedules (objective function evaluations) were used as the stopping criteria in experiments for the first and second problems, respectively.

Table 1: Parameter settings of the PSO

Parameter	Description	Small-Scale Problem	Medium-Scale Problem
i	No. of Birds	1,000	5,000
c_1	Cognitive Parameter	2	4
c_2	Social Parameter	2	2
w_{\max}	Max. Inertia Weight	1.2	1.2
w_{\min}	Min. Inertia Weight	0.4	0.4
v_{\max}	Max. Velocity	3	4

1) Small-scale test instance

Table 2 summarizes the results of the PSO along with the performance of four previous meta-heuristics for the 18-activity problem. Although none of the existing studies reveal the elapsed CPU times, the proposed PSO requires an acceptable CPU time of approximately 1.9 seconds to unravel the first instance by searching a mere $3.39\text{E-}05$ fraction of the solution space. Solutions obtained by Zheng *et al.* (2005) are of inferior quality compared to the results of PSO, since, MAWA-GA's solutions cost 0.9% to 1.55% more than PSO's results. For $D = 110$ days, ACS-TCO of Ng and Zhang (2008) and ACS of Zhang and Ng (2012) provide a solution which costs more than the proposed PSO's result. The Pareto front solutions reported for NA-ACO of Afshar *et al.* (2009) are identical to the results obtained by the PSO method. The comparison of PSO with the state-of-art methods reveal that proposed PSO is among the top performing algorithms for Pareto oriented optimization of the small-scale DTCTPs.

Table 2: Comparison of Pareto Fronts located for Small-Scale problem

Duration (days)	Zheng <i>et al.</i> (2005)	Ng and Zhang (2008)	Afshar <i>et al.</i> (2009)	Zhang and Ng (2012)	PSO (This Study)
100	287,720	283,320	283,320	283,320	283,320
101	284,020	279,820	279,820	279,820	279,820
104	280,020	276,320	276,320	276,320	276,320
110	273,720	271,320	271,270	271,320	271,270

2) Medium-scale test instance

Sonmez and Bettemir (2012) presented a medium-scale 63-activity DTCTP for the single objective cost optimization problem. To our best knowledge, the problem is first solved for Pareto front optimization in this work. Computational experiments of the proposed PSO model involving this instance revealed promising results since PSO was able to locate 38 non-dominated solutions by searching only $7.30\text{E-}37$ fraction of the solution space. Pareto front of this larger instance was achieved within a reasonable CPU time of 37.5 seconds, for the first time. Lack of earlier attempts for Pareto oriented optimization of this problem ruled out a comparative presentation of the results obtained.

CONCLUSIONS

A discrete PSO method for the Pareto front optimization of discrete time-cost trade-off problem is presented in this study. Novel principles for binary representation, and position-updating of the particles are implemented in the proposed PSO method. It is shown that PSO operates to unravel the multi-criteria DTCTP by searching a very small fraction of the search space. The results of the computational experiments reveal that PSO can achieve high quality solutions for a small benchmark DTCTP. For a more complex instance, including 63 activities, PSO was able to obtain 38 non-dominated solutions within seconds, for the first time. The results indicate that the proposed method is among the top performing algorithms, providing a powerful alternative for the DTCTP Pareto front optimization. However, research focusing on generation of large-scale complex DTCTP instances would enable a better understanding of the performance of heuristics and meta-heuristics for the real-life projects. Development of efficient discrete optimization methods for Pareto oriented optimization of large-scale real-life projects appears to be another promising area for the future research.

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SOFT LANDINGS OR A BUMPY TOUCH DOWN?

Steve Donohoe¹ and Jeremy K Coggins²

¹*School of Architecture, Design and Environment, University of Plymouth, Plymouth, UK*

²*School of Natural and Built Environments, University of South Australia, Adelaide, Australia*

Most standard forms of construction contract contain provisions whereby a small value of the Works is retained by an employer known as “*retention money*”. The idea of retention money is to provide funds for Employers to remedy defective work should the contractor refuse or fail to carry out remedial works on a construction project. Most standard forms of construction contract contain requirements that an employer holds retention money on trust for contractors through the opening of a separate bank account for this purpose. Despite specific conditions imposed on employers there are instances where conditions have been ignored which have resulted in complex technical legal issues to be decided in the courts involving the law of equity and trusts. Until relatively recently in spite of the controversies surrounding retention money, the construction industry had to reluctantly accept the situation due to a lack of alternatives. Now, the UK based Building Services Research and Information Association (BSRIA), encouraged by Government, have developed a new technique known as “*Soft Landings*” (SL) which can be used as an alternative to retention. This paper explores the concept of SL in construction through a legal lens which could provide an important future strategic direction for clients and others involved in the modern construction industry. Initial findings are that whilst SL has not been greeted with universal acclaim within the construction industry there is sufficient interest to justify the use of SL as an alternative to the use of retention.

Keywords: construction contracts, procurement, retention, soft landing.

INTRODUCTION

Most standard forms of construction contracts since their inception in the nineteenth century have included payment systems whereby contractors and sub-contractors are paid for their work through instalments. Although no one can accurately trace when this practice began it is understood that the standard form of building contract published by the Royal Institution of British Architects in 1909 included a mechanism whereby contractors were paid following the issue of an architect's certificate which set out in some detail the contractor's entitlement (Dunn, 2011). It is thought that the inclusion of a mechanism for payment by instalments incorporated in the 1909 RIBA was not a new invention but a manifestation of a practice that had developed over a number of years and was accepted by all parts of the construction industry. Allied to the idea of building works being paid for through a system of instalments came the notion that some part of the instalment ought not to be paid immediately but be held back as a protection against defective work or the contractor's failure to complete the project. The part of the instalment not paid over immediately by the employer was, and is, called “*retention money*”. Though building contracts have evolved over the

¹ sdonohoe@plymouth.ac.uk

intervening years the system of paying by instalments subject to a deduction of retention money has remained unchanged to the present day.

This seemingly simple concept of temporary withholding of monies otherwise due to contractors and subcontractors until such time as retention is released has produced controversy and some complex technical legal arguments.

Senior (1991, p241) observed that “[the] objectives of the client, the design team and building contractor are similar in principle and that they differ only in degrees of emphasis and intensity”. Senior (ibid.) maintained that “selfish endeavours” encourage “tactical distribution methods of payment”. It is clear that the use of retention money is one of those methods of payment that might be included within the term “selfish endeavours” when used in context of the construction industry. It is self-evident that the use of retention money causes a loss of working capital to contractors and thus acts a restriction to the contractor’s cash flow. The consequence for the contractor is that the shortfall in cash flow has to be financed usually by overdraft or other borrowing. The consequence to the client is that the cost of overdraft or other borrowing by the contractor is passed on indirectly resulting in a more expensive project than would otherwise be the case. However, as Hackett *et al.* (2007, p32) observed “a balance has to be struck between the maintenance of a reasonable retention fund and easing of the contractor’s cash flow”.

Adriaanse (2007) noted that it is common practice in construction contracts for a small percentage usually around 5 per cent of the value of a certificate to be deducted as retention money and often kept for a period of two years or more. This creates a fund to rectify defects or to persuade the contractor to return to site to remedy defects.

Although a retention money level of around 5 per cent might seem reasonable, contracting parties are under no compulsion to use this percentage and often will amend standard contracts in order to impose retention percentages far in excess of 5 per cent. In the case of *Rayack Co. Ltd v Lampeter Meat Co. Ltd* (1979) a retention percentage of 50 per cent was included in the contract documents. The contractor argued that the retention percentage was excessive and therefore illegal yet the percentage was upheld by the court. Though Murdoch and Hughes (2008, p220) described this as an “unusual case” it shows that parties may use “selfish endeavours” to trap the unwary into agreeing to oppressive levels of retention which can have a catastrophic effect on cash flow.

The decision in *Rayack* establishes the legal precedent that the parties are free to impose whatever retention money percentages they wish. Very high and oppressive retention percentages will not be declared illegal by the Courts if that is what the parties agreed. Strathorn *et al.*, (2014) have characterised construction as an industry which is well known for distrust, cost over runs and conniving intentions as normal manifestations of behaviour. It is submitted that the use of large and oppressive retention percentages does not help to foster trust between members of the construction industry and remains problematic. It has long been acknowledged that the holding of retention money for longer periods than necessary is a major contributor to the high incidence of insolvency in the construction industry (Newman, 1992)

DIFFICULTIES WITH RETENTION MONEY

One of the most basic problems with retention money is the timing of its release. This problem occurs with all stakeholders in the construction contractual chain but it is particularly serious between main contractors and sub-contractors. In the case of sub-

contractors this is particularly acute. For example, a piling sub-contractor who would carry out their work at the beginning of a project may have to wait several months or even years for the release of their retention. Sub-contractors may suffer undue hardship because release of retention may be conditional on matters outside their control, for example the remedying of defects under the main contract between the employer and main contractor.

This problem can be further exacerbated when the release of retention is dependent on the issue of a certificate.

In *Pitchmastic v Birse* [2000] (19981 TCC 159Q) the terms of the sub-contract contained a provision that the retention money be released to the sub-contractor on the issue of a certificate of making good defects of the main contract. However the certificate of making good defects in respect of the main contract was never issued. The question for the court to decide was whether Pitchmastic was entitled to the release of retention in the absence of a certificate?

The Hon. Mr Justice Dyson (as he then was) held that unless Pitchmastic could show that Birse had “*prevented the issue*” of the certificate then on the evidence Pitchmastic's claim (for the release of retention money) must fail.

However it must be observed that Pitchmastic occurred before the passing of the Local Democracy Economic Development and Construction Act 2009 (henceforth “*Construction Act 2009*”) which came into force in October 2011 in England and Wales.

Section 110 (1A) of the Construction Act attempts to prohibit the use of conditional payments dependent on performance of another contract. Whether the wording of Section 110(1A) is sufficient to cover retention money is not entirely clear. What is very clear is that parties may find themselves in a similar position to Pitchmastic who fought a time consuming and very expensive legal battle and still could not secure the quick release of retention money. Furthermore, even if “*retention money*” is caught by the rule against conditional payments under section 110(1A) of the Construction Act 2009, it can be easily circumvented by inserting in the relevant contract or sub-contract a date far in the future so that retention can be held (legally) for a very long time. For example, referring back to Rayack in that particular case the defects liability period was six years in that case. This means that retention money can be legally withheld for very long periods of time seriously affecting cash flow of all participants in the construction supply chain.

After the passing of the Construction Act 2009 there is a risk that a main contractor might be compelled to pay retention money to a sub-contractor before being in receipt of retention money from an employer. However, this ignores the unequal bargaining power of stakeholders in the construction industry, identified by Newcombe (2003), and is unlikely. Although it can be argued that the concept of retention money is simple, it is fraught with legal and technical difficulties.

A further problem arises when one asks the question “*who actually owns the retention money?*” In *Henry Boot Construction Ltd v Croydon Hotel and Leisure Co Ltd* 1986 36 BLR 41 a main contractor (Henry Boot) attempted to protect the retention money through the grant of an injunction against the employer (Croydon Hotel). The court refused to grant an injunction because the amount (allegedly) owed in liquidated damages to the hotel exceeded the amount of retention money. This causes a difficulty because if the case was decided correctly then it would suggest that the retention

money is owned by the employer, but if this is the case, then how can a contractor have recourse to the retention money if there is no ownership?

Standard forms of building contracts have attempted to address the question of who owns the retention money by invoking the law of equity and trusts. Most standard forms contain provisions whereby retention money is held by an employer “*on trust*” for the contractor. Similar provisions can be “*stepped down*” so that a main contractor holds money “*on trust*” for sub-contractors.

Many standard forms such as those issued by the Joint Contracts Tribunal (JCT) include wording that the employer's ownership is “*fiduciary*” which makes the employer a trustee of the retention money. The consequence of this is to separate the retention money from the employer's other money. However it is common practice in the construction industry for amendments to be made to the standard forms (Potts, 2008). In *Wates Construction v Franthom Property* (1991) 53 BLR 23 a provision requiring the retention money to be held separately was deleted from the contract. Nevertheless the Court of Appeal decided that the retention money was fiduciary in nature and ordered the retention money to be set aside. However a further legal issue arose in *Wates* in which the judges had to exercise their minds; namely whether the trustees were under a general duty under the Law (of Trusts) to invest and attempt to increase the value of the retention fund. In the Court of Appeal Bedlam LJ. held that the trustee's duty was to “*safeguard the money*” but [the trustee] has no duty to increase the fund for the contractor's benefit. Whilst the Court of Appeal's decision is to be welcomed in this case, there is still some uncertainty that a Court of Appeal decision could be overturned by a House of Lords (or possibly European Court) decision.

The publishers of standard forms have tried to strengthen the position of contractors and sub-contractors in the construction by a requirement for retention money to be deposited in a separate bank account. This can be particularly important especially in the case of insolvency.

If an employer refuses to open a separate bank account for the retention money then since at least 1979 (Rayack) it is possible to apply for a court injunction to force the employer to open a separate bank account. However this requirement is often deleted, amended or simply ignored. The consequences can be devastating for contractors or those further down the contractual chain. In *British Eagle International Airlines Limited v Compagnie Nationale Air France* [1975] 2 All ER 390 it was held by the House of Lords that parties could not circumvent insolvency laws as this was contrary to public policy.

Although *British Eagle* is not a construction case the authority of the House of Lords means that it is applicable to contracts generally, including construction contracts. In terms of retention money, what this means is that unless separate trust accounts can be proven to exist then any money irrespective of its nature or purpose will be considered part of the assets of the insolvent party and will be shared amongst unsecured creditors. This emphasises the importance of establishing separate accounts or obtaining injunctions quickly. An example of the difficulty that can happen can be seen in *MacJordan Construction v Brookmount Erostin Ltd* 1991 56 BLR1 CA. In this case the employer, Brookmount Erostin, experienced financial difficulties and went into Administration. The contractor, MacJordan, worried that it might not be able to access retention money sought an injunction compelling the employer to set up a separate bank account. It was held that the contractor was too late and that an

injunction could not be issued on the grounds that insolvency proceedings had commenced.

The circumstances in MacJordan might be regarded as a technicality, as the issue involved one of timing rather than a legal issue. However, once again it reinforces the idea that the concept of retention money is difficult. It is cumbersome for contractors (and /or sub-contractors) to have to apply to the courts for an injunction on every single project they undertake in order to protect their entitlement to retention money.

In summary the problems with retention money in construction contracts are identified as:

Length of time retention is held and unjustifiable reasons for withholding

Unsettled questions arising from operation of the Construction Act 2009

Unsettled questions of ownership and control of retention money

Legal complexities of Trust Law

Complications due to Insolvency Law

The need to obtain injunctions to protect retention money

The timing of the application (for injunctions)

According to a UK Government report about £3 billion of retention money is held across the construction industry at any one time (H.M. Government, 2008)

SOFT LANDINGS

Until recently there was an unofficial consensus in the construction industry that whilst there were problems with retention as a concept, nothing much could be done about it. More recently The Building Services Research Information Association (BSRIA) encouraged by the UK Government has developed a new approach to assist the construction industry and help its clients to deliver better buildings. This new approach is called “*Soft Landings*” (SL).

SL is a radical new idea which eliminates the need for retention in construction contracts.

SL attempts to solve the performance gap between the intention of designers and the experiences of users. BSRIA observed that a performance gap can emerge at any stage of a building project including inception and briefing; design and specification; construction; hand over and commissioning and occupation.

BSRIA see SL as a “*culture change*” and can apply to both new build and retrofit projects. It is a step by step process for clients and their consultants and contractors to avoid the pitfalls associated with most building projects The SL philosophy requires a “*buy in*” from all participants in the construction supply chain and expects participants to be involved and stay involved far beyond the traditional hand over at practical completion.

SL uses a five stage process which is shown below:

Soft Landings Five Stage Process

Stage 1: Inception and briefing

The time for constructive dialogue between the client, the designers and the potential constructors about intentions, performance requirements and stakeholder expectations. Embedding specific SL activities in the client’s requirements and tender

documentation and setting aside budget for aftercare and post-occupancy evaluation. Effort should be made to get key specialist advice earlier than would be the norm- controls specialists, commissioning engineers, facilities managers, key sub-contractors- catering, ICT, lighting and controls integrators ; nomination of SL Champions to drive the process forward ; and reviewing past experience to inform design. [Emphasis added]

Stage 2: Design development and review

Brings the entire project team together to review insights from comparable projects and detail how the building will work from the point of view of the manager and individual user. Agreeing the energy strategy – and the metering and monitoring strategy and the approach to commissioning and ensuring they are regular items for discussion and covered in relevant tenders. Review the proposed systems for usability and maintainability and reality-check as systems turn into actual installed products.

Stage 3: Pre-handover

Graduated hand over enables operators to spend more time on understanding interfaces and systems before occupation. Revisit the outputs from earlier reality-checking decisions and ensure the suggest actions are in place. Ensure Building Management System (BMS) is set up the way the client intended- energy data reconciliation and data storage, and the energy monitoring software. Also ensure the metering is working properly and will deliver real insights into energy use.

Stage 4: Initial aftercare

The project team to be resident on site between six and eight weeks to spot emerging issues. Go walkabout regularly and chat to people, find out how systems are operating and whether they meet occupants' expectations and actual requirements. Adjust where necessary and report back. Help the asset managers understand what they have inherited. Measure and monitor but don't rush to make a judgement.

Stage 5: Years 1 -3 extended aftercare and Post Occupancy Evaluation (POE)

The period of longer-term less intensive monitoring and support. Involves a series of aftercare review meetings, monthly to begin with but could quickly become quarterly. Ensure that the energy monitoring is set up and working well. Conduct systematic POE no sooner than 12 months post-handover, repeated at 12 month intervals and culminating in a final project review at month 36. (After BSRIA, 2014)

This change is an attempt to alter traditional practice after practical completion where most of the contractor's personnel leave the project with perhaps a small number returning to site to rectify defects on occasions to a situation where all or most of the contractor's personnel remain on site after practical completion for the purpose of assisting the employer's staff in the smooth running of the building.

It is proposed that an important part of the SL approach is the use of Post Occupancy Evaluation (POE). Where POE has been done on past projects this has normally been carried out by the employers own staff or by consultants engaged by the employer. It has been relatively rare for contractors and/ or sub-contractors to be involved in POE. An SL approach seems to suggest a much more prominent role in POE for contractors and subcontractors to play in the future.

It is acknowledged by BSRIA that the inclusion of a budget to cover aftercare and POE might be seen as a significant extra cost for construction clients. It is also conceded by BSRIA that the calculation of an allowance is difficult as it will vary

from project to project. Nevertheless BSRIA maintain that the inclusion of money in the client's budget represents value for money when set against the cost of complex litigation involving retention money. BSRIA are aware of the need for flexibility and have developed a strategy known as Government Soft Landings (GSL) for use in public sector construction projects. BSRIA explain the difference between SL and GSL in the following terms

Government Soft Landings (often called GSL) is not an integrated and collaborative client/delivery team process like BSRIA Soft Landings, but more a set of facilities management-driven requirements for a well-performing building. Although there is a debate as to the precise demarcation of SL and GSL what is clear is that all participants in the UK construction supply chain involved in public sector projects will be affected by “*Soft Landings*” in one form or another. Although this paper is confined to the exploration of SL from a UK industry perspective, Bunn (2015) reported that an Australian and New Zealand version of SL (termed “*ANZ Soft Landings*”) has recently been launched for use in those countries. This means that SL may become a significant feature in the international construction scene in future.

METHODOLOGY

According to Gomm (2008, p15) the idea of doing research is “*to provide readers with vicarious experience of other people's lives*”. Thus in the context of Soft Landings the research adopts an interpretivist stance following the view of Seymour *et al's* who felt that it is not necessary to critique the use of causal relationships in findings in every piece of construction management research (Seymour *et al.*, 1997).

People are reflexive and make choices and decisions continuously which determine outcomes (Brown and Phua, 2011). In this research the aim is not to deliver a fully worked out, prescriptive agenda for SL which the author would argue is neither desirable nor practicable. Rather the research is of an exploratory nature which attempts to provide insights into authenticity and aspirations of those involved or likely to become involved in SL. This approach is grounded in the idea formulated by Burr (1995) who explained that the research process is a co-production between themselves (the researchers) and the people they are researching. Rossman and Rallis (2003) advocated that the typology is one which can “*go to the people*”.

In carrying out this research the human dimension is at the forefront of this work indeed the dimension is regarded as a central tenet of the work. Winter (1996) felt that our working lives are a never ending sequence of judgements and stressed the importance of the human dimension. As such the work must include treatment of the legal and technical framework which underpin the examination of SL in the context of construction projects whilst understand that emotions, feelings, attitudes and experiences have a part to play. It must be acknowledged that for some members of the construction supply chain the adoption of SL is not a matter of choice as it will become mandatory from 2016 in public sector contracts. Naturally those who find the entire idea of SL to be abhorrent may seek to “*opt out*” through withdrawal from the public sector market, however given the composition of the construction industry (i.e. majority of firms are small) it is unlikely that mass withdrawal will actually happen. It is against the backdrop of the above that the research procedure was adopted. The researchers used an approach proposed by van Manen who investigated linking knowledge with ways of being practical (van Manen 1977). The investigation was carried out by a series of interviews with stakeholders. The use of interviews is a commonly recognised research method (Mason, 1966) whose strengths arise due to a

“richness and vividness of material (Gillham, 2000) Patton (2002) concurs with these views and opines that the strength [of interviews] lies in their ability to yield responses about experiences, opinions, feelings and knowledge. Keats (2000) felt that interviews gave more dynamic responses to static questionnaires.”

A total of twenty one interviews were carried out. The interviewees comprised three representatives from different sectors of the construction industry including clients; architects; surveyors; engineering; main contractors; specialist sub-contractors and general sub-contractors. For reasons of time and economy of resources all interviewees were chosen from the South West of England.

Transcripts were collected and the contents analysed on the basis of contextual themes.

DISCUSSION

“It became apparent from the analysis that whilst the concept of retention money was universally understood, some interviewees (more than one third) admitted that they had never even heard of “Soft Landings”. (Interviewee 20 – General Subcontractor) “Soft Landings? - Never heard of it but anything that gets rid of retention is a good idea in my book”. This is an interesting claim because although the interviewee said that he knew nothing about SL, he knew sufficient to understand that an SL scheme replaced retention. Other sub-contractors appeared to give tacit approval to SL but were wary of the attitude of main contractors towards SL. (Interviewee 17 – Specialist Sub-contractor) “Look unless it’s a legal requirement [main] contractors are not going to play ball. It’s too much in their interest to hold the money for as long as they can. We [sub-contractors] are financing their business and at the end of the day they [main contractors] are going to find a way round it”. This concurs with the view stated by another sub-contractor (Interviewee 16 – Specialist Sub-contractor) who felt that the process had to be “client driven”. When probed as to the meaning of this phrase he said that the success or otherwise of SL depended on a spirit of cooperation between clients, consultants, contractors and sub-contractors. He predicted a situation whereby clients and contractors might use SL but main contractors would not relinquish their right to withhold retention from sub-contractors and this in the opinion of Interviewee 16 “sows the seeds of its own destruction”. Despite the dramatic language expressed by this interviewee it is tolerably clear that the issue of trust between members of the construction supply chain plays an important part in the successful launch of SL.

All three representatives gave a “cautious welcome” to the idea of SL. Two of the three expressed concern about the potential perceived extra cost of the “aftercare” service. Interviewee 1 (Company Director) said that SL set off “alarm bells” and added “It’s [SL] a great idea in theory but we can’t just be seen to be issuing a blank cheque. At least with retention we have a cushion, but I as understand it, we pay upfront (for SL) but how do we know the bloke [contractor] will not just disappear and we get taken for a ride?” Although one cannot generalise the sentiments would accord with Sandelowski’s idea of a credible study which are “faithful descriptions of human experience that people living that experience would immediately recognise it from their descriptions” (Sandelowski, 1989. p30). Once again it would seem that the issue of trust is important in the SL arena.

Of the three contractors who were interviewed one was very enthusiastic about SL (interviewee 15) but it later transpired that the particular contractor was a member of

the BSRIA Soft Landings membership group. The other two interviewees claimed to have heard of SL but stated that their knowledge of the scheme was limited. A similar narrative was offered by the consultants with some enthusiastic and others openly hostile. It would appear that from this small scale study that SL polarises opinion. One worrying finding was that two of the engineers (Interviewees 10 and 11 respectively) claimed not to have heard of SL. This is strange as most members of BSRIA are engineers. It is likely that as SL is rolled out to the public sector then all consultants, not only engineers, will become familiar with SL. This is not to downplay the potential legal difficulties especially where the parties are not in a bi-partite contract. For example, it is entirely foreseeable that the “*aftercare and POE*” functions which are central to the SL arrangement are outsourced or carried out by third parties. The “*standard*” legal position since the decisions in *D&F Estates v The Church Commissioners* (1989) AC177 and *Murphy v Brentwood District Council* (1991) AC398 is that a contractor or sub-contractor does not owe a duty of care in respect of economic loss. In contrast designers and (possibly) other consultants have been treated differently following precedents derived from *Hedley Byrne v Heller and Partners* (1964) AC465 based on “*special relationships*” between parties. Clearly this has implications for SL and wider questions of liability and insurance cover.

CONCLUSIONS

The foregoing has revealed extensive practical, technical and legal problems concerning the concept of deduction of retention money from members of the construction supply chain. Soft Landings represent an imitative that has been launched in order to promote better buildings and is immediately at odds with the traditional use of retention in contracts. The Soft Landings approach has not found universal approval from all within the construction supply chain however it is a major part of the UK Governments strategy for construction. There are some difficult issues concerning legal liability to be addressed however it is conceivable that Soft Landings will play a major role in the UK construction industry in the years ahead.

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PRE-CONTRACT ASSUMPTIONS IN PRACTICE: A QUALITATIVE STUDY ON THE FLEXIBILITY TO CHANGES IN DBFM CONTRACTS - BLANKENBURGVERBINDING PROJECT CASE STUDY

Hatice Cigdem Demirel¹, Wim Leendertse² and Marcel Hertogh³

^{1 and 3} Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, The Netherlands

² Ministry of Infrastructure and Environment, The Netherlands and University of Groningen, Groningen, The Netherlands

PPPs (Public Private Partnerships) are a range of possible relationships between public and private parties. They are realized mostly in contexts of great uncertainty. A challenge in PPPs such as DBFM (O) (Design, Build, Finance, Maintain, Operate) contracts or projects is how to keep the contract progression efficient when there is a high degree of uncertainty. The purpose of this paper is to discuss the potential of changes and requirement of flexibility in a DBFM contract through a case study and to present recommendations for future DBFM contracts. An extensive literature review on the subject of changes and flexibility is provided. Furthermore, this paper describes the results (analysis) of 32 interviews conducted in relation to the case study, the Blankenburgverbinding project. The main findings show that change recognition and flexibility perspectives in pre-contract phase provides the client and stakeholders a better understanding of the challenges facing the organization in realizing its aims and delivering a DBFM project in its complex environment.

Keywords: complex environment, contract changes, DBFM, PPP.

INTRODUCTION

A lack of understanding of the complex environment in which PPP contracts are being created is a significant contributor towards large sunken investments or project failures. Understanding this complex environment of PPP in the pre-contract phase is especially important for decision makers, where the proposed project may become more complex due to changes during the construction and maintenance phases. Therefore, a focus on establishing the right delivery of a project regarding the change expectations, matched to the complexity of the environment of the project, is vital for effective project management.

This research addresses the results of the Blankenburgverbinding (BBV) case study as a part of larger research. It presents the results of the first in a series of case studies regarding Rijksaterstaat DBFM projects in the planning, realization and exploitation phase. Rijkswaterstaat is the executive agency of the Ministry of Infrastructure and Environment in the Netherlands. The focus of this study is to analyse the practical implementation issues dealing with changes in DBFM contracts (during the realization

¹ hcigdemdemirel@gmail.com

and exploitation or maintenance phase) and identify measures that can be taken in the pre-contract phase to deal with potential changes for certain categories of projects. These measures may reduce conflict and result in a more efficient management (added value) during the construction and maintenance phase of the DBFM(O) contracts.

In PPP contracts, neither its activities nor its environment is stable. What was state-of-the-art yesterday may be out of date tomorrow (De Neufville and Scholtes 2011). PPPs will always be affected by changing circumstances. Sun and Meng, *et al.* (2009), Verweij (2014), Hao *et al.* (2008), Hwang and Low (2011) argue that changes are inevitable in construction projects. Therefore, PPP contracts include change procedures (Rijkswaterstaat 2014; Highways Agency 2010). These procedures provide a reactive way to specify and evaluate project changes when they occur. A DBFM(O) contract is considered a type of PPP or PFI (Private Finance Initiative) contract which facilitates private investment in public infrastructure/assets often over 20 to 30 years. Kwak *et al.* (2009) pointed out that PPPs are not easy to apply to infrastructure projects due to their contractual arrangement complexity and high level of uncertainty that arises from the long concession period. Changes can result from political, economic, social, technological or legal circumstances.

The business of construction projects brings together different types of organizations and stakeholders. These organizations and stakeholders are interrelated by contracts and specifications in order to deliver the service as intended. The relations between the project and its actors (the complex environment) encompass what potential changes may be expected. The contract should provide measures to deal with these “*potential*” changes (scenarios). However, construction projects are influenced by different strategies and procedures from multiple associated actors. As a result, the consideration of change is a very important part of the contract mechanism, especially in DBFM contracts, due to the long-term relationships. It is a common experience that stakeholders in complex projects are the major source of changes (Ward and Chapman 2008). Effective project management involves understanding sources of both uncertainty and complexity to formulate appropriate management strategies (Ward and Chapman 2008; Hertogh and Westerveld 2010).

There is a growing body of PPP literature concentrating on the pre-contract phases (Levy 2011; Chan and Cheung 2014). Most of this research is focused primarily on identifying the causes and effects of changes and how to cope with them (Sun and Meng 2009; Hwang and Low 2012; Price and Chahal 2007). It is important for decision makers to know and understand how to deal with the various types and sources of changes especially in long term contracts like DBFM. However, research related to DBFM implementation and practitioners’ views of the changes in DBFM contracts is scarce (Lenferink 2013). This paper describes the potential lifecycle changes as identified by the client and stakeholders of the BBV project - a DBFM contract in the Netherlands currently being planned. The purpose of this research and case study is to discuss and compare the client and stakeholders’ perceptions regarding potential changes and the need for flexibility with the literature especially in DBFM contracts, to present recommendations for future DBFM contracts.

LITERATURE REVIEW

Expected changes in literature

The significance of the complex project environment is recognized in literature (Hagan *et al.* 2012). However, there is limited research addressing the changes in a

DBFM contract context. De Neufville (2011) presented uncertainties in engineering design and argued why flexibility in design is needed. Koppinen and Rosqvist (2010) developed a project portfolio selection method to assist infrastructure managers in optimizing the life cycle profiles of their assets through selection of an optimal maintenance and repair portfolios based on the level of both existing and expected uncertainty. Wu *et al.* (2005) proposed a classification based on multiple-case studies using statistical analysis to identify change in a highway project in Taiwan, to clarify the causes of construction changes and to analyse their influence. Their intended aim was to give a reference to clients in forming their project procurement strategy. Sun and Meng (2009) presented the classification of changes in an adopted hierarchical structure. At Level 1 the causes of changes are divided into three broad categories; external, internal and organizational causes. Level 2 explains the determining factors of changes such as environmental, social and political factors and Level 3 describes the root-cause of the changes. A review of the salient literature about expected changes in infrastructure projects provide a number of categories. In the literature several authors categorize changes in different ways. The categorization as used in Table 1 were generally derived from the reviewed literature.

Contract flexibility in literature

Several publications have appeared in recent years documenting the flexibility of contracts on topics such as contract law, finance and relational issues (Domingues *et al.* 2014; Cruz and Marques 2013; Nystén-Haarala *et al.* 2010). De Neufville and Scholtes (2011) have tackled flexibility from a technical point of view for engineering design projects. They provided an overview detailing why flexibility in design is needed to deliver significantly increased value. Domingues *et al.* (2014) examined contractual flexibility in transport infrastructure PPPs and found that flexibility is more likely to contribute to the project's success when implemented in the contract design. According to Nystén-Haarala *et al.* (2010) flexibility is often introduced to life cycle contracts with relational methods, relying on good personal relationships between business partners. They also stated that the contract documents do not often contain mechanisms for dealing with contingencies. Saleh *et al.* (2009) proposed to transform flexibility into a quantifiable engineering attribute and grow the concept to a level of maturity. An interesting approach observed by them that the concept of flexibility is “*vague and difficult to improve*” compared to the notion of quality 20 years ago. Barton (2015) documented two perspectives of flexibility: legal and business. He argues for a multi-national approach to examine flexibility and international legislation and the need for deeper collaboration between those drafting and implementing the contracts. The results are highly enlightening and suggest a greater need for a broader international study on the issue of flexibility in contracts.

In some cases, uncertainties are ignored by decision makers. Therefore, the resulting consequences could be devastating with unpleasant surprises in the long term (Stahl and Cimorelli 2005; Perminova *et al.* 2008). Hertogh and Westerveld (2010) stress the need for adaptive management, which is characterized by monitoring and evaluating results and adjusting actions on the basis of what has been learned. This means that there should be a strong feedback link between monitoring and decisions, which allows for effective learning. The initial arrangements should facilitate this.

In general, relevant literature is mostly concentrated on legal and financial issues of contract flexibility but is scarce in relational issues.

CASE STUDY

The Blankenburgverbinding (BBV) Tunnel Project

The BBV will provide the main highway connection between the highways A15 and A20 in the Netherlands (Figure 1). The distance covered by the project is short - only 5 km of highway - but it is highly complicated with an immersed tunnel crossing the intensely used Nieuwe Waterweg and a 1.5 km land tunnel crossing a very sensitive populated area. The decision to realise this connection, was taken after decades of political discussions and the evaluation of many alternatives for this route. The BBV is one of a series of projects planned for the sustainable future development of the Rotterdam region (Rotterdam Vooruit 2009).

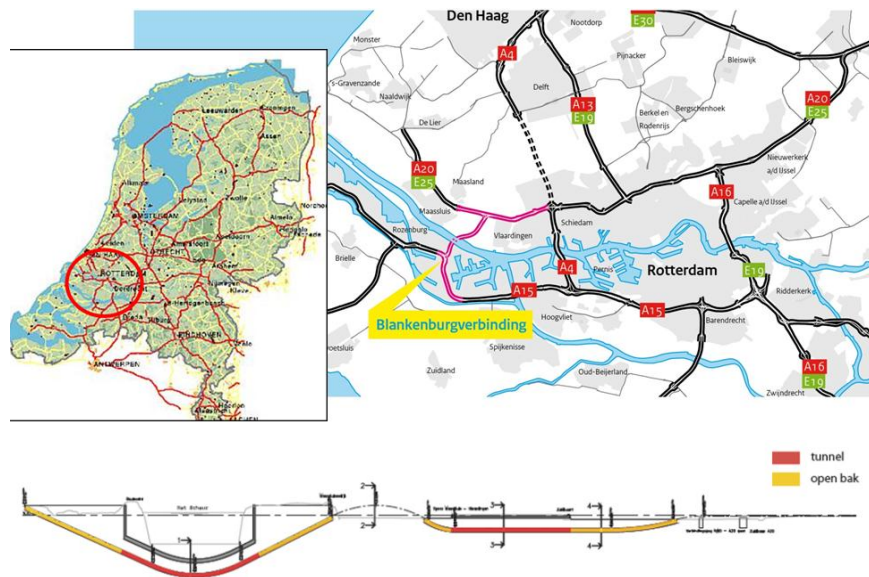


Figure 1: The

planned Blankenburgverbinding (BBV) in the Rotterdam area (see also www.blankenburgverbinding.nl)

The purpose of the BBV is to provide a robust infrastructure connection for the western part of the Rotterdam Harbour complex and supply a traffic solution for the growing river crossing traffic. In 2013, the total contract costs were estimated at approximately €1,000 million. The project will be partly financed by toll. The BBV will be contracted as a DBFM contract. The construction will start in 2017, and the expected opening is in 2022. Besides realization of the project, a maintenance period of 20 years is contracted starting after construction phase.

Due to the complex environment of BBV, including a large number of actors, (major) changes can be expected during the DBFM contract period. The interrelationship of actors and complex nature of the BBV project are shown in Figure 2. The ability to adapt to changes in this complex environment including current and future stakeholders is required. This paper is limited to currently involved actors and focuses purely on a specific set of dominant current actors illustrated in the cloud of Figure 2.

The DBFM Contract Form in the Netherlands

The Dutch DBFM contract model is influenced (extended) from Anglo Saxon contract nature. There is no specific legal structure for Dutch PPP contracts. A standard DBFM(O) contract model for infrastructure was developed by Rijkswaterstaat (Rijkswaterstaat 2014). They have also standardised the tender guidelines for the

procurement proceedings. The competitive dialogue procedure is used to award complex public DBFM(O) contracts.

The Data gathering through interviews

Semi-structured interviews were used for qualitative data collection. The interviews started with a predetermined and phrased set of questions to explore specific issues within the research project (Naoum 2012). However, the questions were more general in their nature; and the sequence of the questions varied per interviewee with new questions evolving during the interviews (Bryman 2012). The interviews concentrated on the following main questions:

1. What kind of changes did you experience in your existing projects?
2. What kind of changes do you expect for the BBV Project?
3. Does the DBFM change procedure cope with the changes?
4. Is a DBFM contract flexible in your opinion?
5. What is your understanding from flexibility in DBFM contracts?

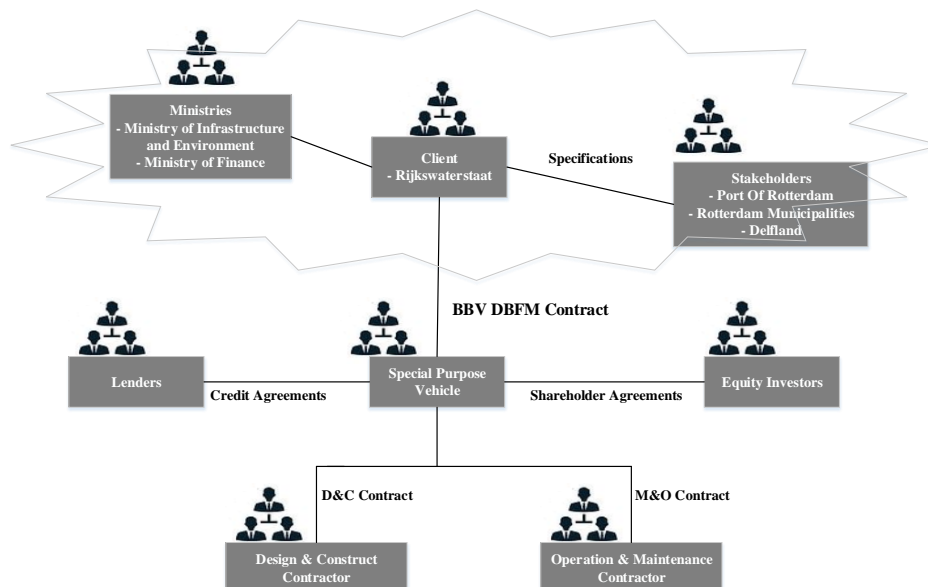


Figure 2: Blankenburgverbinding (BBV) dominant DBFM project actors

The interviews illustrate how practitioners' from different organizations explain and understand the potential changes specifically in relation to the context of the BBV project and particularly the DBFM project. Furthermore, the interviews gave insights into how to cluster and level the changes and increase the understanding of how planners can deal with a complex environment, especially in DBFM contracts. A total of 32 interviews were conducted between April and July 2014. The data gives insight into the different perspectives of the stakeholders. Twenty nine Dutch stakeholders from the Ministry of Infrastructure and Environment, Rijkswaterstaat, Municipality of Rotterdam; Water Board of Delfland and the Port of Rotterdam were interviewed. A further three interviews were conducted in the UK with the Highways Agency for the purpose of comparison. All the participants held senior positions regarding risk, contracts, environment, technical services, assets, projects, law, advisory, and changes. Braun and Clarke's (2006) thematic analysis approach was used to systematically code and analyse the interviews. The codes for the categorization of changes were defined prior to the interviews based on the literature review. Sub codes evolved while analysing the transcripts (see Table 1).

FINDINGS

All of the 32 interviewees characterized the environment in which the BBV project is established as complex. Especially the dynamic environment of the Rotterdam area and the political emphasis on the development of the main port of Rotterdam were mentioned (see Table 1). This corresponds with Aaltonen and Sivonen (2009), who argue that stakeholder conflicts are among the most significant unforeseen risks in projects implemented in challenging environments. Similarly, Hertogh and Westerveld (2010) argue that most dominant form of complexity experienced by practitioners in large infrastructure projects is social. There is a tendency for public participants to ignore potential changes. Ignorance leads to reaction instead of proactivity. The unawareness of uncertainty is consistent with the inflexibility documented in the literature by Stahl and Cimorelli (2005) and Perminova *et al.* (2008) and by the participants in practice.

On the whole, all the interviewees suggested expected changes to the BBV project. However, the focus of expected changes was mostly in the realization phase of the project. The participants' understanding of DBFM contracts centred mostly on that of a D&B contracts with additional maintenance. Short term requirements rather than the life-cycle and facilities management of the asset is where the major concerns are expressed. Most participants did not realize the effect of changes in DBFM under the incorporated life-cycle mechanism. In the interviews, 68% of the changes related to the Design and Build phase and 32% towards the Design, Build and Maintenance phases.

It was generally agreed that understanding the potential changes can help both public and private project managers to deal with them in the construction and the maintenance phase. In Table 1* the change categorization as derived from the literature is related to the findings of the interviews in the BBV case. The categorization can be used as a basis for further detailed investigation into uncertainty. The findings should be viewed as a generic template that will be further expanded.

Stakeholders and client understanding of flexibility changes from person to person. Flexibility in DBFM projects is assessed from two different perspectives. When one says a contract is flexible, the statement conveys mostly legal understanding that the contract clauses can easily deal with the changes. However, this understanding does not deal with the complex environment of PPPs. The interviewees' who approached flexibility from a business-managerial perspective stated that each stakeholder has a role to play and some will be more dominant than others. For example, contractors are obliged to pay their loans in time to lenders. Having contractual flexibility does not imply that the complex environment of tight relations between actors will make the project more rigid. They stated that uncertainties can be dealt with in any type of contract but because of the actor relations, cost and time issues in DBFM type of contracts call for flexibility. The majority of interviewees (74%) stated that DBFM contracts are flexible regarding their change procedures. However they also indicated that this can result in significant schedule and cost issues. Additionally, the minority (16%) believed changes are difficult to impose on DBFM contracts. Furthermore, the remaining (10%) was not sure due to their unfamiliarity with the DBFM contract.

The interviewed contract managers viewed flexibility as an essential ingredient for success of DBFM projects because they are long term investments in a complex environment. Client's procurement procedures with their service providers need to be more flexible in the dialogue phase regarding potential changes. Stakeholders said that

flexibility and contract efficiency can be provided with good communication between the actors. Those who approach contracts from more relational perspective argued that “we should sit on the same table with client and service provider over the contract period to build up good relations and express the needs.” This is in line with Haarala’s (2010) findings as flexibility introduced to contracts with relational methods relies on good personal relationship between the actors. Saleh *et al.* (2009) stated that flexibility, despite its popularity, is not yet an academically mature concept and the interviews show this is also the case in practice. The different perspectives correspond with Barton (2015), who reported flexible contracting in two different and seemingly opposed perspectives which are legal and business oriented.

Table 1: Change categorization

Changes in construction projects Literature	Feature	Expected changes in a DBFM project Case Study
Influential surrounding projects	Changes in project environment	Accidents in other tunnels (5/32)
		Hit by ships (2/32)
		Residential changes (Immigration) (5/32)
		New exits for residential areas (10/32)
		Surrounding highways (10/32)
		Surrounding railways (5/32)
		Surrounding cables and pipelines (4/32)
		New dykes (5/32) Port facilities (5/32)
Global Crisis Lack of public financing Bank accounting systems Fluctuations in annual budgets	Financial Changes	Toll prices, Toll cuts (13/32)
Specifications and law Noise and vibration restrictions New proposals for reducing green gas emissions	Changes of Legislation	New national tunnel standards (12/32) EU standards (12/32)
Governments make new laws Tax paying issues	Change in politics	Change in decisions (10/32)
The movement towards the service based system Boundary conditions Collaboration of parties Risk sharing Level of competition Contractor selection Responsibilities	Organizational changes	Rijks waterstaat organizational changes (10/32) Risk sharing (12/32)
Efficiency and effectiveness Environmental requirements Performance measures Safety requirements Mobility requirements Quality levels	Changes of requirements	Environmental requirements (11/32) Quality levels (10/32)
Global warming Sea level Water conditions	Climate changes	Water conditions (5/32) Weather conditions (3/32)
Use of new materials Car technology	Technological changes	Technology (8/32)
	Traffic system	Traffic management system (7/32) Traffic density (3/32) Speed limits (3/32)
	Technical Changes	Tunnel installations (3/32)

* Number of times issue was mentioned in the interviews compared to total numbers of interviews

Private participants were not interviewed yet in this case study. Participants (client and stakeholders) stated that contractors bear no responsibility for these kinds of changes, therefore their response is mostly reactive instead of proactive. Introducing changes and flexibility approach in pre-contract and the tendering phases (like the competitive dialogue) may force private parties into a proactive attitude. This was also suggested by the client and stakeholders as a better example of a solution through the dialoguing and pricing of options.

DISCUSSION AND CONCLUSIONS

The initial investigation of the BBV leads to the following conclusions which support the need for a flexible approach to the PPP contract. Firstly, top managers and specialists involved in the BBV-project are unanimous in their expectation that many changes will occur during DBFM project lifetime. The expected changes are mostly related to changing politics and the dynamic environment (stakeholders). However, there is a tendency, especially by public clients, to ignore expected changes and rely on the flexibility of the contract.

Secondly, the BBV case study corresponds with the change categorization as found in literature. However, changes are by the large focussed on the short-term realization phase. The majority of interviewees consider the DBFM contract as a D&B contract with additional maintenance. In general, actors do not realize that changes can occur during the whole life-cycle mechanism with significant consequences, high contract disturbance and cost implications when changes occur. Reactive management to the maintenance phase may result in further financial burden on the PPP actors or client.

The interviews stated that both the client and stakeholders should identify proactive measures necessary to deal with expected changes. Reaction leads to inefficiency and disturbance of the project progression. Better to act proactively on possible changes.

Furthermore, there was a wide range of views from the interviewees regarding flexibility which reflects the current level of flexibility in academic and practical contexts. The understanding of flexibility is changing regarding technical, legal, financial and actor relationship perspectives. This increases the complexity. Future research will gather a better understanding of flexibility from each disciplines viewpoint.

Within quantitative and qualitative studies we take into account stakeholders perceptions on expected changes and flexibility for complex DBFM projects. This data will be used in the competitive dialogue tendering of the BBV DBFM project. The findings give insights and support the alignment of the client and Special Purpose Vehicle (SPV) and their capability to meet the degree of changes during the implementation and maintenance phases of the contract. Additionally, this helps DBFM actors to understand their current delivery environment and then create the one they need. Furthermore, this will help to allocate project risks to the parties best able to manage them. For each party, risk allocation is interesting which is consistent with changes and has sufficient flexibility to deal with them. Classified changes from stakeholders' perspectives can be a useful starting point for the development of a risk framework. Specifically, these expected changes can be directly related to the availability of fees in the DBFM contract which stands within the schedule of the contract. From the SPV side, being prepared to make these changes will reduce future difficulties repaying loans to the banks.

This study demonstrates the need for a common language and understanding of popular words used in DBFM contracts to tackle the complexity. The derivation of a definition of flexibility as well as guide to flexibility is an area within DBFM projects that needs further attention. The concept of flexibility is observed as vague in DBFM projects.

FURTHER RESEARCH

The novel aspect of this study compared to the reviewed literature is that expected changes with great effect under DBFM are related to possible counter measures in the pre-contract phase. Future data will be gathered through more case study research to judge whether the overall complexity is low, medium and high, because different changes can carry more weight in DBFM projects than others. Further case studies will also look at the perception of flexibility in different stages of a project. The exploration phase of A12 Dutch Highway DBFM contract will be examined as a next step. It will be interesting and useful to explore the flexibility approach regarding the relations between the actors in the exploration phase of DBFM projects to better inform the approach towards the BBV DBFM contract and compare the results with the findings identified in the planning phase of the BBV project.

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OWNERSHIP OF MATERIALS: A SCOTTISH/ENGLISH DICHOTOMY

Ian Trushell¹ and Siobhan Morrison

School of Engineering and Built Environment, Glasgow Caledonian University, UK

Materials are a critical element within the construction industry yet the conditions and legality surrounding their ownership remains an area of uncertainty. The difficulty in ascertaining ownership is often found in the instances of payment, delivery and complex contractual relationships. Additionally, the nature of the construction industry whereby raw materials are purchased within a supply chain and are incorporated into the fabric of buildings or goods often creates further confusion. The importance of ownership is most apparent in the instances of disputes or insolvencies, both of which are regular occurrences within the construction industry and also in the management of a project with respect to cashflow and programme. This research aims to evaluate current law regarding ownership of materials in Scotland through the undertaking of a literature review which establishes the prevailing legal structure to inform the position and stance of Scots Law in relation to ownership of materials. Conclusions and recommendations propose it is imperative that parties are aware of current law surrounding the intricate matter regarding ownership of materials in Scots Law.

Keywords: insolvency law, liquidation, ownership, sale of goods, Scotland.

INTRODUCTION

Materials are the fundamental ingredient to a construction project. However, ascertaining who holds ownership of materials can be decidedly difficult within the numerous and complex contractual arrangements of the construction industry. Construction projects are a multidisciplinary process due to the nature of the 'product' and industry as a whole. One single project can involve many disciplines and the creation of several interfaces between each of the parties involved, resulting in a complex supply chain and the development of many contractual relationships. The importance of contractual relationships is crucial when asserting the rights attached to each party to administer the contracts effectively and in resolving disputes, should they arise. Disputes are recognised as a consistent and regular occurrence within the construction sector, arising from numerous and varied situations. Research by Malleson (2013) reveals there is a market trend which indicates the level of disputes has increased over the last few years and both industry bodies and disciplines believe construction disputes will continue to increase. The litigious atmosphere of the construction industry is magnified in times of decreased availability of work due to an unstable economic climate. As a consequence of the recent economic situation, a number of firms had entered into insolvency proceedings and members of the construction industry are continuing to protect themselves against the risks associated with liquidation. Beale and Mitchell (2009) confirm that insolvency is a prominent

¹ i.trushell@gcu.ac.uk

and threatening occurrence within the present day construction sector and advise it is imperative that those involved within a project protect themselves regarding the payment and ownership of materials.

Additionally, payment of materials has a direct effect upon cashflow within a project. Cashflow is paramount in construction projects and is frequently documented as being directly linked to delayed programmes, having an impact upon project delivery and contributing to a deterioration in working relationships. A reduction in cashflow for any one project also has an effect on other projects the Contractor may have running concurrently within his business. The certainty of payment for materials is therefore of crucial concern for cashflow purposes and overall management of a project and a business.

The legal conditions surrounding payment of materials is determined by a number of factors. Variables include whether the materials are located on or off site, fixed or unfixed to the works, and both when possession and ownership of property is transferred and who retains that ownership at the various stages of the process. The determination of these points differs dependent on the legal perspective and structure prevalent within the country where work is taking place. The intricate details and legal requirements regarding ownership of materials is one such matter whereby the legal difference between English and Scots Law becomes apparent. Thus, construction works are not only accountable to a contract but also to the common law and system in place within the country and transactions must adhere to the relevant protocols and legislation.

With consideration to the foregoing, this research will focus upon the often contentious subject area concerning ownership of materials within the legal context of Scotland with an aim to evaluate current Scots law practice.

EVALUATION

Scots Law

Scots Law is fundamentally derived and deduced from the laws and doctrines of ancient Rome. The legal structure within Scotland is of a deductive nature based upon the institutional writers who adopted Roman law which Walker (1982) identifies as being constituted of three separate principles; the laws of persons, things and actions. This is in contrast with the inductive legal system practiced within England whereby case law and judgements accumulated over many years form a chain of judicial precedents which determine current practice, largely based upon the most recent court decision.

Within Roman law there was a distinction and difference established between 'things' and 'actions,' or correspondingly, sale and hire. The division of these legal principles was reflected in the practice of separate contracts for each component, which Connolly (1999) argues becomes problematic within the context of building or construction works, as it poses the question of whether the contract will be a contract of hire, purchase and sale, or both. A contract of sale relates to the purchase of goods and is regulated by the Sale of Goods Act 1979 (Uff, 2009). Section 2 (1) of the Act defines a sale of goods as 'A contract by which the seller transfers or agrees to transfer the property in goods to the buyer.' Interestingly, this definition does not specify payment or delivery as determining factors that would constitute a sale. The implied notion is that of intention, whereby the seller 'agrees to transfer the property.' Also notable within this condition is the absence of any services; the contract is for the sole

purpose of the purchase and sale of goods. The separation of contracts of hire and sale does not explicitly accommodate for all possible transactions that could occur. For example, a contract of hire may result in the production of 'goods' yet a contract of sale may not have necessarily occurred. An attempt to remedy this situation was made with the introduction of the Supply of Goods and Services Act 1982. Scots Law was accommodated by the Sale and Supply of Goods Act 1994 which contained provisions for matters relating to the Scottish legal system.

Ownership of Materials

The intricate nature of construction contracts in Scotland as a developed form of Roman principles is distinctive in respect of hire and sale; however, there is historically an absence of particulars relating to the ownership of materials. The question of whether ownership and title to materials passes upon payment, delivery or intention is a matter in which much deliberation is present, yet which can only be ascertained by thoroughly investigating each circumstance.

The complication of ownership with regards to delivery is dependent on the type of contract used. A contract of sale, or supply only contract, would allow for property in goods to pass upon delivery, but the nature of a construction contract is not that of only sale. The combined hire, or supply of services creates an effect in which delivery alone cannot allow transfer of ownership. Within the Scottish judicial precedent of *Seath and Co v. Moore* [1886] 13 R 57 HL Lord Watson stated;

'Materials provided by the builder...although intended to be used in the execution of the contract, cannot be regarded as appropriated to the contract or as 'sold' unless they have been affixed to or in a reasonable sense made part of the corpus.'

Evidently, this case displays that sale and hire must both be considered complete to allow for the transfer of ownership. The ruling indicates that in addition to delivery, there is a condition that labour and incorporation of the materials must have taken place. Bell (1899) reaffirms that '...the articles sent are merely the materials, the act of delivery seems not to complete till the work be performed'.

With respect to intention, Section 6, 11B (1) of the Supply of Goods and Services Act 1982 introduced implied terms to facilitate the right to transfer title; 'In a contract for the transfer of goods...there is an implied term on the part of the transferor that...he has a right to transfer the property.' This condition reinforces the terms expressed within the Sale of Goods Act 1979 which specified the seller 'agrees' to transfer title, thus supporting the notion of intention and agreement to transfer. Additionally, the Supply of Goods and Services Act 1982 also implied a term to allow for 'quiet possession of goods,' whereby, the Purchaser, or Employer, is legally permitted to possess the goods without interference from other parties, including claims for ownership.

Regarding payment, Murdoch and Hughes (2008) inform that the general consensus at common law is that ownership of materials transfers to the Employer when materials are incorporated into the works, whether or not payment has taken place. As this matter is complicated by the varied contractual relationships within the construction industry, it is prudent to establish the relationship and whether payment within the supply chain alters, or indeed constitutes, the transfer of ownership.

Contractual Relationships

The contractual relationships effective within a project play a vital role in ascertaining who owns title in goods and subsequently who, therefore, has the authority to transfer those goods. Furst and Ramsey (2006) note in the traditional structure of a project there is an Employer, Contractor and one or more Sub-contractors. Any or all of the parties mentioned can be involved in further relationships with Suppliers. Common law recognises the difference between the role of a Sub-contractor, who provides both goods and labour, and a Supplier, who supplies only goods. This complex supply chain creates numerous contractual relationships where parties are not necessarily in direct contract with one another. Murdoch and Hughes (2008) explain that historically, the legal doctrine concerning Privity of Contract would not allow a third party with no contractual relationship to enforce contract terms. Within construction contracts, it is regular practice that Employers and Sub-contractors have no contractual relationship. However, the Contract (Rights of Third Parties) Act 1999 has sought to remedy the situation.

The traditional Employer and Contractor relationship typically involves the Employer engaging with the Contractor to carry out the works inclusive of supply, a relatively straight forward relationship. The Employer can also enter into a contract of purchase and sale with a Supplier for an item to be incorporated into the works and contract another party to install or incorporate that item. A Contractor can then in turn procure either; the services of a sub-contractor, supply of materials and services from a sub-contractor, or the supply of goods from a Supplier. The distinction between each of these roles and relationships is crucial when deliberating who rightfully holds ownership to materials. Adriaanse (2010) considers that issues regarding ownership of materials are most likely to arise in the relationships Contractors have with Sub-contractors and Suppliers. He proposes the difficulty predominantly lies within the likelihood that the Contractor does not acquire the right to the goods which lawfully prohibits him in turn to sell on to a third party, e.g., the Employer. Failure to obtain ownership is a circumstance known as the 'nemo date' rule which Adriaanse (2010) explains means that 'a person cannot give better title than he or she has.' In the event of a Contractor purchasing goods from a Supplier, Section 25 of the Sale of Goods Act 1979 states ownership rights to the goods are specified to have passed;

'Where a person having agreed to buy goods obtains, with the permission of the seller, possession of the goods...the delivery and transfer by that person...of the goods...receiving the same in good faith...right of the original seller of the goods.'

Transfer of ownership is conditional upon 'good faith' and there can be no reproach on the basis of a retention of title clause.

Successful application of Section 25 is demonstrated in the case of *Archivent Sales and Developments Ltd v Strathclyde Regional Council* [1985] SLT 154. Strathclyde Regional Council had employed R.D. Robertson (Builders) Ltd as the Contractor for the construction of a school. Robertson had engaged in a supply-only contract with Archivent for the purchase of multiple ventilators which contained a retention of title clause stipulating that property in the goods would not pass to the customer until payment had been received in full. Robertson took possession of the goods which had been delivered to site by Archivent. Strathclyde Council certified and made payment to Robertson for the goods, unaware of any title reservation clause. In accordance with their contract, payments for materials within an interim certificate become property of the Employer. Robertson received payment from Strathclyde Council but did not pay

Archivent for the supply of the ventilators before going into receivership. Archivent, the Supplier, requested return of the materials, or payment, from Strathclyde Council. Presiding Lord Mayfield held that in terms of the contract between the Supplier and Contractor, the intention for ownership to pass was upon payment in accordance with a sale of goods contract. However, the possession of the materials by the Contractor, who acted as a 'mercantile agent' not out with the regular and accepted practice of construction transactions and subsequent delivery to the Employer, was evidence enough to satisfy that ownership had transferred to Strathclyde Council. Section 25 of the Sale of Goods Act 1979 prevailed over a retention of title clause in this instance and as had occurred previously in the case of *Thomas Graham and Sons Ltd v Glenrothes Development Corporation* [1968] SLT 2. Lord Mayfield's judgement made much reference to this case and of particular interest was Lord President Clyde's statement declaring;

'Section 25 is a statutory recognition of an exception to the general rule that only an owner of goods can transfer the property in them. The section enables an apparent owner to transfer someone else's goods to a third party in certain specific circumstances.'

This statement highlights that the Sale of Goods Act 1979 acknowledges there may be substantial reasoning in favour of the third party for ownership to transfer depending on the particulars of the case. The nature of some transactions, such as those performed in construction, allows an agent to effectively assume ownership thus enabling them to transfer the title of those goods.

The cases demonstrate the importance of ascertaining who holds ownership to materials if a party becomes insolvent. MacQueen and Thomson (2012) define insolvency as 'the inability to meet obligations as they fall due because total liabilities exceed total assets.' This definition encompasses the various different forms of insolvency; administration, receivership and liquidation, which are all subject to the Insolvency Act 1986. Essentially, a company or person is insolvent if they are unable to finance their obligations and there are also repercussions for parties they are involved with as found in the case of *Archivent Sales and Developments Ltd v Strathclyde Regional Council* [1985]. Watt (2010) reaffirms that when Liquidators become involved, recovery of goods or money becomes challenging and exceedingly unlikely, therein lies the risk within the construction industry and the importance of realising who retains ownership of goods.

State of Materials

In addition to the complexities surrounding contractual relationships, a further consideration is the circumstances in which an ownership dispute is occurring, i.e. whether the goods or materials supplied have been transformed or incorporated into the works or where they are located or stored at the time their ownership is debated.

Materials that have been incorporated into the fabric of the building under common law are considered property of the Employer and ownership is deemed to have transferred. Payment for the materials need not have taken place as Watt (2010) confirms that incorporation regardless of payment is sufficient for ownership to transfer. Conversely, in the event that materials are on site but have not yet been incorporated into the works, the situation becomes more complex and requires further investigation to determine whether ownership has indeed passed from a Supplier or Sub-Contractor to the Contractor or Employer, or whether it has been retained. As demonstrated in the cases of *Archivent Sales v Strathclyde Regional Council* [1985]

and *Thomas Graham and Sons Ltd v Glenrothes Development Corporation* [1968], a Supplier is unable to claim ownership of the materials if they have been included within an interim payment certificate. In the event of a Contractor's insolvency and in spite of a reservation of title clause, the Supplier will have no claim for unfixed materials on site if they have been included within main contract payments. Brewer (2004) advises that in this situation the Supplier or Subcontractor remain very much 'at risk for the value' of those unfixed materials which have been paid under the Employer and Contractor main contract, yet no payment has been received by those bearing the risk.

Contrary to the aforementioned cases, an important decision in England which illustrates the differences between English and Scots Law, took place in the case of *Dawber Williamson Roofing Ltd v Humberside County Council* [1979] 14 BLR 70. The decision resulted in amendments to the Joint Contracts Tribunal (JCT) standard forms of contract to provide security for Employers in disputes regarding ownership of materials. A supply and fix contract existed between the subcontractor Dawber Williamson Roofing and Taylor and Coulbeck, the Contractor, who were employed by Humberside County Council. Dawber Williamson had been prevented from commencing works as the project was behind schedule, but nonetheless Dawber supplied and delivered to site the roofing slates required in preparation to begin. Taylor and Coulbeck applied and received payment for the roofing slates from Humberside Council prior to their liquidation, although Dawber had not received any payment for the materials they had supplied. Upon knowledge of Coulbeck's liquidation, Dawber sought to retrieve the slates from the site, from which Humberside refused them access on the argument that the slates were now their property following their inclusion in the interim payment certificate of the main contract. Dawber maintained that the supply and fix contract did not entail 'selling' the materials to the contractor, and until they had been fixed to the structure and paid for, then ownership remained with them. Humberside relied on the defence that the main contract terms were incorporated into the subcontract. Furmston (2012) details it was held that the nemo date rule applied in this case as the contractor could not transfer property of the materials to Humberside Council as they had never acquired title in the first instance and secondly, Humberside's argument regarding the main contract terms becoming effective within the subcontract were insufficient as there was no privity of contract established between Dawber and Humberside. Dawber were successful within this landmark case in English Law which instigated amendments to JCT standard forms of contracts to provide a level of security for Employers who would otherwise bear the risk for materials that they had paid for, but which had not yet been incorporated into the works. The revised terms stated that once materials or goods are delivered to site by a Subcontractor and included within the main contract interim certificates, the Subcontractor shall not 'deny that good title has passed to the employer' (Brewer, 2004).

When materials are located off site on premises not belonging to the Employer, common law in Scotland dictates that property to the materials will not have passed. *Stirling County Council v Official Liquidator of John Frame Ltd* [1951] SLT 37 is the leading and most prominent case which expressly determined Scots Law regarding this scenario. John Frame Ltd were employed by Stirling Council for construction works in a housing scheme. Due to limited space on site Frame stored, with the knowledge and permission of Stirling Council and their Architect, materials in a locked storage container in their yard, off site. Upon Frame's liquidation, Stirling

Council attempted to retrieve the materials on the basis that Condition 5 of their contract expressed that 'From the time they are placed upon the site... all materials delivered by the Contractor for the execution of the works, shall become and be the absolute property of the Employer.' Sheriff-Substitute Walker held that a building contract was not one of sale, and as such the Sale of Goods Act 1979 was not applicable, and moreover the title of the goods had not passed in this instance. With regards to Condition 5, he declared it was not enforceable and was in his opinion 'remarkable' and 'under reference to some foreign system of law,' to which the legal system of England is the supposed inference. He further added it was 'conclusive' that Condition 5 was not applicable and furthermore, that Stirling County Council had not acquired any title to the materials. Upon appeal, Sheriff-Principal Black agreed the contract was not one of sale and disputed the pursuer's argument that the materials were 'constructively on site' to establish that there are two distinct stages which must be adhered to in order for property of the material to transfer. These stages consist of possession by placing materials on the site and delivery by incorporation into the works. He proceeded to explain that in storing the materials off site, they were subject to the control of the Contractor and could not be considered as being 'delivered for the execution of the works' in any manner. The Sheriff-Principal was very much in agreement with the Sheriff-Substitute in all matters concerning this case. The Employer and pursuant, Stirling County Council, were unsuccessful and did not receive recompense upon the Contractor's insolvency for materials paid for and located off site on the basis that delivery to site had not taken place. This case was significant within Scots Law regarding payment for materials off site and caused the Royal Institution of Chartered Surveyors Scotland to advise this issue to be particularly highlighted to their clients upon the first payment certificate, as (Bowles and Gow, 1992) inform that payments from local authorities at that time were being made for up to 90% of the value of materials with no knowledge of who held ownership. However, the Regulations and practice by many remained unchanged after the case ruling.

Ownership of materials that have undergone transformation, or have been included within a manufacturing process to become another product entirely, are subject to the specifics of each case. Webb (2000) professes that law courts have 'consistently' maintained that once a transformation has occurred, the original goods are non-existent and consequently, the claim to title or property for them is 'extinguished'. An example demonstrating Webb's declaration would be the much referred to case of *Aluminium Industrie Vaassen BV v Romalpa Aluminium* [1976] 2 All ER 552 whereby a contract of sale existed between a Dutch Supplier of aluminium foil to an English Purchaser with the intention of using the foil within a manufacturing process. The Purchaser took possession and used a quantity of the foil within the process, however, before providing full payment for the goods the Purchaser became insolvent. The appointed Receiver sold both mixed and unmixed materials upon the insolvency and the pursuer argued that ownership had not passed in the goods as full payment had not been received. It was held that title had not passed. However, the unmixed foil that had been sold was now the property of the new buyers and the pursuer could claim the proceeds of the sales.

A further demonstration that goods cease to exist due to being irretrievably mixed and transformed within *Borden (UK) Ltd v. Scottish Timber Products Ltd* [1979] 3 WLR 672 in which the retention of title clause was rendered ineffective as the resin supplied had been incorporated into chipboard and was considered to no longer exist.

Conversely, this line of argument was not successful within another Scottish case, that of *Armour v Thyssen Edelstahlwerke AG* [1989] SLT 182. In this case, Thyssen retained ownership on the basis that title had not passed as the materials had been worked upon, but they were not irretrievably transformed. Therefore, if small changes have occurred to the goods there may be grounds for retaining ownership, if, however, substantial changes have taken place or other goods have been mixed, there is little chance of retaining title as a new product has been made (Hicks 1993).

Preventative Measures

Accepted practice in construction is to eliminate or mitigate risks and financial losses which align with the sentiments of Vella (2009) who advises that each contractual party should do everything within their power to ensure there is effective security and protection within their transactions to continually reduce their exposure to risk. There are options available to the contractual parties to accommodate for ownership of materials and provide a level of protection for themselves in the event of any party's insolvency whilst maintaining effective management of the project.

A retention of title clause serves the purpose of delaying the transfer of ownership until certain criteria have been fulfilled, namely payment, which Morse (1993) suggests protects the supplier of goods from insolvency of the purchaser. Once materials or goods have been incorporated into the works, a retention of title clause no longer applies. The distinction between Sub-contractor and Supplier is important within the contractual arrangement as a Sub-contractor may present a claim without a retention of title clause, whereas a Supplier may only claim in the event of a retention of title clause. The most secure situation for a Supplier is, as Beale and Mitchell (2009) propose, to refrain from delivery unless full payment has been received or ensure the retention of title clause is applicable. In order for the clause to be effective the direct customer and any third party, such as the Employer, must be aware that a retention of title clause is in operation. As demonstrated within *Archivent Sales v Strathclyde Regional Council* [1985] a retention of title clause will not protect an unpaid Supplier if the third party purchases the materials in good faith with no prior knowledge of the clause. This, however, can only be effective to an extent, or be subject to conditions, as the ruling of *Aluminium Industrie Vaassen v Romalpa* [1976] established. The intricate nature of construction contracts and the supply chain has enabled a necessity for clauses such as a retention of title to provide a level of assurance and security. Bradgate (1987) believes the main complication is, in fact, the legal systems and their struggle of 'reconciling the several decisions on the subject.'

In order to transfer ownership prior to delivery, the Employer in Scotland may enter into a Contract of Purchase, separate from the main contract which becomes a contract of sale only and, therefore, subject to the Sale of Goods Act 1979. The finished goods purchased using a contract of this type are omitted from the main contract and the contract sum is adjusted accordingly by deducting the value of the purchased goods informs Frame (2011). According to MacRoberts (2008), Contracts of Purchase are particularly appropriate on occasions where a specialist may require payment for manufacturing or restoring products within his own premises. Some goods in construction are manufactured entirely off site and brought to site for installation or erection only. Steelwork and pre-fabricated forms of construction rely upon either; a separate Contract of Purchase and Sale, or the Contractor allows for the financial burden of these items until they are delivered to site and eligible for inclusion in interim payments.

Another option, specific to English Law and JCT standard contracts, is the provision for off-site materials or goods bonds which incorporate a defined schedule of 'listed items' whereby payment for those items is conditional upon transfer of ownership to the Employer. However, MacRoberts (2008) cautions that these terms are not applicable in Scots Law, as it cannot be displayed that title to the materials or goods has indisputably transferred. The Scottish Building Contracts Committee have accommodated for this within their contracts.

As a final option, again specific to English Law, Vesting Certificates are commonly used to transfer the title in materials or goods and provide protection to the owner. Materials and goods are separately identified and securely stored in facilities off site. Struckmeier (2009) warns that Vesting Certificates are not applicable in Scots Law as they will not have the same validity. Evidence of applying English law sentiments within Scotland where they have no jurisdiction or foundation within Scots Law can be found in Sherriff-Substitute Walker's comment in the case of *Stirling County Council v Official Liquidator of John Frame* [1951] whereby he remarked the contract condition was in reference to some 'foreign system of law.'

CONCLUSION

The legal structure prevalent within Scotland has been established and investigated to determine the nature of construction contracts and subsequently, the conditions applicable to the transfer of ownership of materials in Scots Law. Ownership of goods transfers upon incorporation into the works or delivery as was determined with a degree of finality in the landmark judicial precedent of *Stirling County Council v Official Liquidator of John Frame* [1951]. Such transactions in Scotland are subject to either the Sale of Goods Act 1979 or Sale and Supply of Goods Act 1994. The options and risks for each party have been explored in addition to the conditions which constitute a transfer in ownership.

In the construction industry, and indeed in each country where construction operations are taking place, it is imperative that upon entering a contract for construction works that all parties are aware of their responsibilities and entitlements. Attention to the contract conditions and to the prevailing legal structure and current law is essential to fully protect parties against any instances of material ownership dispute which are most likely to arise in instances of insolvency. The complex and intricate nature of the construction industry which trades in high value transactions and investments, combined with high instances of insolvencies and disputes in an adversarial atmosphere, results in little room for error and it is essential that those involved are fully aware of the legalities surrounding ownership of materials.

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RESOLVING INFRASTRUCTURE-RELATED CONSTRUCTION DISPUTES IN DEVELOPING COUNTRIES: THE GHANA EXPERIENCE

Joseph Mante¹

The Law School, Aberdeen Business School, Robert Gordon University, Aberdeen, UK

The last three decades have witnessed increased investment in infrastructure projects and construction activities in developing countries. Unfortunately, disputes often arise from such projects in developing countries that are resolved by arbitral tribunals in the developed world. Whilst similar projects in the developed world also suffer from the problem of costly disputes, there is a growing trend of resolving them by less costly ADR methods. Available literature on infrastructure-related construction dispute resolution in developing countries provide inadequate information on how such disputes are resolved in practice. The qualitative study, which formed part of a larger study on infrastructure-related construction dispute resolution in developing countries, critically examined construction dispute resolution experiences of Ghana as a typical example of practice in developing countries. The aim was to identify problems with the extant dispute resolution process and explore possible improvements. Ghana was used as a holistic case study. The study relied on interview data. Semi-structured interviews were conducted with forty-five top management employees of five Government Ministries and six public institutions regularly involved in major construction projects. Additionally, eleven individuals from foreign construction firms and adjunct organisations were also interviewed. Data collected were analysed using grounded theory-related analytical methods such as coding, memoing and diagramming to develop themes and patterns from the data. It was found that high dispute resolution cost, low satisfaction with outcomes and suspicious relationships characterised the extant dispute resolution process. An attempt is made to proffer ways to address the challenges identified. The research will enhance foreign contractors' understanding of dispute resolution practices in developing countries and contribute to research by adding to the limited literature on the subject.

Keywords: developing countries, dispute resolution, infrastructure development, Ghana.

INTRODUCTION

The past three decades have witnessed burgeoning research on the relationship between economic growth and infrastructure development. Research conducted in Sub-Saharan Africa (Forster and Briceno-Garmendia 2010; Osotimehin *et al.* 2010), East Asia (ADB *et al.* 2005), and Latin America (Andres *et al.* 2008) have all established a positive correlation between infrastructure development and economic growth. Briceno-Garmendia *et al.* (2004) found that reliable and affordable infrastructure can reduce poverty and thus help achieve the Millennium Development Goals. Using a regression framework, Calderon and Servén (2010) conducted an empirical assessment of the impact of infrastructure development on growth in Latin America

¹ j.mante@rgu.ac.uk

and found that there is a growth cost to the infrastructure gap in the region. Reviewing other studies on the relationship between infrastructure development and growth, the authors concluded that infrastructure development had the potential to promote growth and equity under the right conditions. Consequently, it is not surprising that States and Multilateral Development Banks (MDBs) are investing more resources in infrastructure development in developing countries across the globe (World Bank 1994; UNCTAD 2008).

With increased construction activities, disputes have been inescapable. The perception is that many of such disputes arising out of infrastructure projects in developing countries are resolved by arbitral tribunals in Europe mainly as a result of lack of efficient framework for dispute resolution and the absence of relevant knowledge, infrastructure and expertise (Mante, 2014). Available literature on construction-related dispute resolution in developing countries, especially those in Africa, provides inadequate information on the existing framework for construction dispute resolution. Public infrastructure development is essentially the preserve of States and is often undertaken by foreign construction firms (UNCTAD, 2008). Consequently, the main parties to construction disputes, the kind this study focuses on, are the State and foreign consultants and contractors. The study aims to identify what framework exists for construction dispute resolution in the context of major infrastructure projects involving the State. Using existing literature, a conceptual model for construction dispute resolution was developed to guide the study. The next section examines this framework. This is followed by an outline of the research approach and a discussion of the outcome of the research.

FRAMEWORK FOR CONSTRUCTION DISPUTE RESOLUTION

Two observations on construction dispute resolution stood out in the relevant literature. Firstly, the process covers a broad perspective embracing the determination of rights and obligations of parties as well as dispute avoidance, reduction, control and management. Secondly, the techniques employed to achieve the above goals are often ordered on a continuum ranging from techniques supporting cooperation between parties to those authorizing third party intervention. The continuum also depicts levels of control that parties and or third party neutrals have over the resolution process at different stages. Powers transferred to third party neutrals may be facilitative and/ non-binding (as in mediation) or binding (as in arbitration or expert determination). Fenn *et al*'s (1997) taxonomy for conflict and dispute resolution illustrates the first observation – it categorizes dispute handling processes in construction into conflict management and dispute resolution processes. Dispute review boards, negotiations, quality matters and procurement systems are all classified as conflict management strategies. Dispute resolution is categorized into binding and non-binding. However, it is worth noting that the focus of their research was (in part) to provide taxonomy of dispute mechanisms not a framework reflecting how these mechanisms are applied.

The second observation is typified by Cheung's (1999) framework for dispute resolution - this goes beyond providing taxonomy of dispute processes. Following Groton's (1992) stair-step chart, the various resolution mechanisms commonly used in the construction industry are set on a continuum and indication given as to the stages where respective processes are used (Cheung, 1999). He categorizes the process into dispute prevention (where the emphasis is on equitable risk management and cooperation) and resolution. At the base of the stair are the prevention processes. As disputes escalate, they are moved on to the resolution phase which begins with

negotiations. Cheung (1999) divided the dispute resolution phase into four stages namely standing neutrals (dispute review boards, dispute resolution adviser etc.), non-binding processes (mediation, mini-trial and adjudication), binding mechanisms (arbitration) and litigation. In his view, the four categories of mechanisms follow each other lineally along the stair-step. This may not always be the case in practice as parties may choose to mediate even whilst litigating.

Nevertheless, Cheung's (1999) framework broadly reflects the views of many experts on construction dispute resolution. For instance, Hinchey (2012) proposes a dispute resolution framework which emphasizes avoidance strategies and advocates for the use of standing neutrals, non-binding mechanisms and binding mechanisms respectively when avoidance fails. Cheung's (1999) framework also largely reflects what pertains in practice as could be observed with the multi-tiered dispute resolution frameworks found in all the major standard form contracts for engineering and construction works such as the FIDIC and NEC3 suites of contract. From the review, it is posited that modern construction dispute resolution revolves around three main concepts namely dispute avoidance, management and determination/resolution and a good construction dispute resolution framework will often reflect aspects of all these concepts. Avoidance focuses on preventing the emergence of the dispute all together or reducing its occurrence. Dispute management focuses on nipping disputes in the bud as soon as they emerge. Finally, resolution focuses on helping the parties to address disputes themselves or with the help of a third party (either agreed or imposed). In effect, the problem of disputes is tackled at every stage of the project cycle (see Figure 1 below).

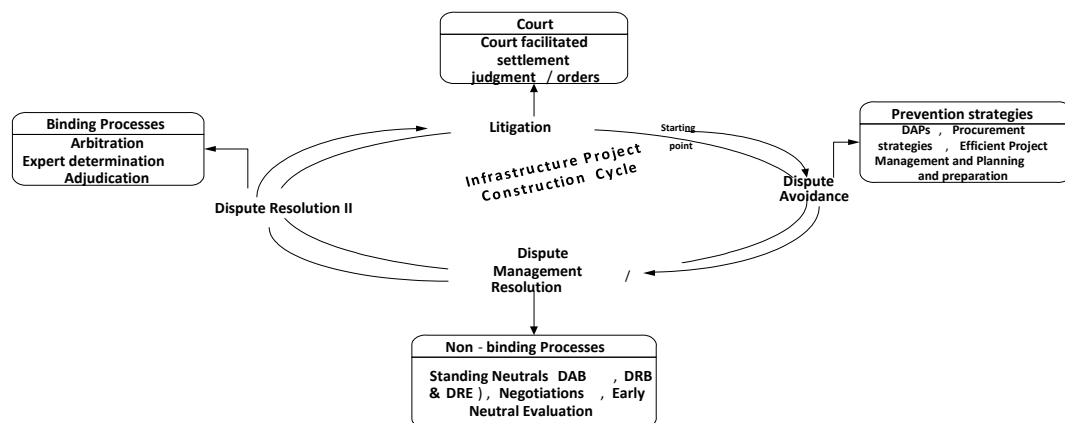


Figure 1: Framework for Dispute Resolution (Source: Literature)

Consequently, the focus of the study was to explore the extent to which the processes of infrastructure-related construction disputes involving the State and foreign contractors reflected the concepts captured in the above framework. To achieve this aim, this aspect of the larger study had a single objective namely to inductively explore the process of dispute handling from the perspective of participants in the industry to identify building blocks of the extant construction dispute resolution framework.

RESEARCH APPROACH

Given the aim and objective of the study, a qualitative approach underpinned by an interpretivists' philosophical paradigm was adopted. As Neuman and Krueger (2003) noted, the goal of this paradigm is to understand social phenomena through the eyes of participants. This approach was useful in view of the general lack of prior research on

the subject of investigation. With Ghana as a holistic case, the study relied on views of participants in major infrastructure construction activities involving the State and other public entities. Semi-structured interviews were conducted with forty-five employees of five Government Ministries and six public institutions regularly involved in major construction projects. Additionally, eleven individuals from foreign construction firms and adjunct organisations were also interviewed. Participants were selected based on their previous involvement in major public infrastructure construction activities and experiences with construction disputes resolution. The semi-structured interviews followed Patton's (1990) general interview guide technique and were organized into four sections covering themes such as the procurement process (choosing dispute resolution mechanisms), disputes and the resolution process. This report primarily examines the theme on dispute resolution.

The analysis of the data was thematic. Data obtained from the interviews were transcribed, edited and coded for concepts and subsequently, themes. The coding process which was accompanied by memoing was in three segments namely open, axial and selective. The initial coding process broke down the data into chunks generating a total of 89 codes. These codes were examined for the different dispute resolution processes in use. A total of ten mechanisms were identified at this stage from the data coded (see Figure 2 below). Several other concepts identified at this stage (including "*selection*", "*cost*", "*delay*" and "*neutrality*") were found to be associated in different ways with the ten resolution processes identified.

Consequently, the second phase of the coding, explored further the connections between each of the ten concepts representing various ways of addressing construction disputes and the remaining concepts through the data. Using the concept of "*international commercial arbitration*" (ICA) as an example, it was discovered after further examination of the data that concepts such as "*neutrality*", "*fairness*", "*cost*", "*delay*" and "*destruction of relationships*" had been used in relation to ICA in different contexts. The first two had been used in relation to factors considered when selecting ICA, whilst "*cost*", "*delay*" and "*destruction of relationships*" were identified as characteristics of ICA in the Ghanaian context. Concepts which were linked to ICA in similar ways were grouped and assigned a broader label which encapsulated the nature of the connection. Thus, concepts such as "*fairness*", "*neutrality*", "*enforceability*", "*confidence*" and "*funding*", for instance, were clustered under the sub-category called "*selection of ICA*".

As more links were established and explored during the memoing process, a storyline on the extant framework for construction dispute resolution began to emerge. The final stage of the analysis explored patterns in the data for how the different resolution mechanisms identified fit into a common framework. On the basis of what parties agreed and frequency of use, three categories of dispute resolution mechanisms were found. The themes, patterns and narratives which emerged from the qualitative data analysis are discussed below.

DISPUTE RESOLUTION MECHANISMS

The first of the three categories of dispute resolution processes identified from the data were mechanisms which the parties agreed at the contract stage and eventually utilized regularly. These were Engineers' determination, negotiations (amicable settlement) and international commercial arbitration (ICA). The second category of dispute mechanisms were agreed by parties at the contract stage but were rarely used. These were mediation, dispute adjudication boards and expert determination. Then

there was a third category of dispute resolution mechanisms which were not agreed by parties but were ultimately utilized to resolve disputes, namely litigation and informal third party interventions (see Figure 2 below).

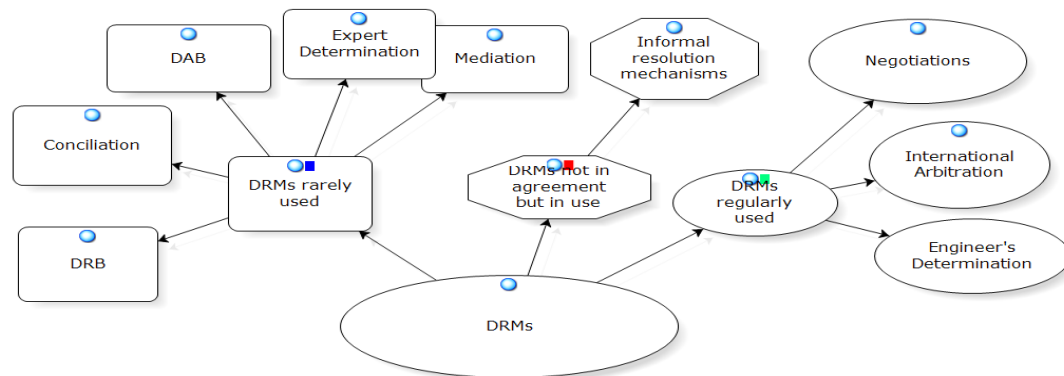


Figure 2: Dispute Resolution Mechanisms (DRMs) in use (Source: Field Data)

Predictably, the three dispute resolution mechanisms regularly used by parties to major infrastructure projects in Ghana were the same as those outlined in the fourth edition of the FIDIC Red book, 1987, the commonly used standard forms. Parties generally stuck to dispute mechanisms agreed at the beginning of their contractual relationships. On limited occasions, parties employed other mechanisms such as mediation, conciliation, expert determination and DAB with varying results. The existing dispute resolution process was beset with numerous challenges. Contractors generally loathed the quasi-judicial role of the Engineer under the Red book, 1987. The reasons for this are well documented (Ndekugri et.al 2007). In the context of Ghana where the transactions were mainly government projects, this dislike was exacerbated by the fact that the Engineer was often a government department.

The introduction of Dispute Adjudication Board as a replacement for Engineer's determination under the new FIDIC Red book, 1999 had not yet made the needed impact. Disputes encountered related mainly to projects executed under the fourth edition of the Red book. Even for the handful of projects utilizing the new FIDIC Redbook, 1999, the use of DABs was hampered by lack of adequate knowledge of the workings of the process, lack of policy direction and guidelines for its use by government departments and the cost implications of maintaining it throughout a project cycle. International commercial arbitration, the other right-based dispute resolution option was a mechanism of last resort for a number of reasons. For contractors and the Employer in particular, it was an expensive choice characterized by delays, general dissatisfaction and destruction of relationships (see also Asouzu 2001).

Moreover, parties underutilized the amicable settlement period. At best, they attempted negotiations. At this stage, contractors were often in a hurry to escalate disputes to ICA outside the jurisdiction of the employer. The employer, on the other hand, though desirous to settle disputes internally, lacked adequate knowledge and skills to apply or encourage the use of intermediary dispute resolution processes such as mediation, conciliation and DABs. Further, the absence of legal obligation on parties to attempt amicable settlement under the FIDIC arrangement meant that parties did not have any contractual or legal reasons to make the most of the period of amicable settlement. To this extent, the period provided for amicable settlement under the FIDIC arrangement was merely cosmetic. The introduction of the process of

amicable settlement after a determination by an Engineer or a DAB meant that parties approached the process at a time when they had been sharply polarized by the earlier determination. Where the issues between the parties were finely balanced on the merits, the aggrieved party would have already signalled its intention to proceed to international arbitration. The implication was that the amicable settlement process counted very little.

Again failure of parties to identify in advance ADR mechanisms to be used during the amicable settlement period meant they only had to do this when they were already involved in a dispute and had little or no appetite for collaboration. It is submitted that the issues with construction dispute resolution in Ghana were symptoms of a bigger problem with the dispute resolution framework for major projects. Dispute resolution was considered as a matter for the back-end of the project cycle. Disputes became an issue only when they emerged during and after the project. Parties paid little attention to disputes and related issues at the initial stages of the project.

DISCUSSIONS

The modern approach to construction dispute resolution as reflected by the framework (see figure 1) requires parties to start thinking about disputes right at the commencement of and during the project (Vorster 1993; Diekmann and Girard, 1995). Parties to projects pursue dispute prevention and management approaches in addition to the use of resolution mechanisms agreed in the contract (Fenn *et al.* 1997; Cheung 1999; Hinchey 2012). Dispute avoidance approaches focus on the initial stages of a project and aim at ensuring that the parties start right so as to reduce or prevent the occurrence of disputes (Vorster 1993; Yates and Duran 2006). The literature identifies a broad range of dispute avoidance techniques most of which fall under one of the following four areas namely the use of standing neutrals, procurement and relational contracting; effective project management; and project planning and preparation. The last three avoidance methods are not considered alternative dispute resolution mechanisms. They focus on avoidance rather than resolution per se. On the first set of techniques, Gerber (2000) identifies three main standing neutrals or Dispute Avoidance Procedures (DAPs) namely the Dispute Resolution Adviser (DRA) (or the Project Neutral/Dispute Resolution Expert (DRE)), Dispute Adjudication Boards and Dispute Review Boards (see also Cheung and Yeung 1998; Harmon 2003; Yates and Duran 2006). The last two are often referred to collectively as Dispute Boards.

The second set of avoidance techniques uses procurement and related processes to manage relationships so as to avoid disputes. The essence of this approach is that maintaining good relationships and healthy communication links among project teams engenders cultural shift from adversarialism to cooperation. It is envisaged that such change in project environment encourages parties to resolve their differences more easily and thus avoid disputes. Examples of this set of techniques are partnering, alliancing, integrated project delivery systems and equitable risk allocation (see Bresnen and Marshall 2000; Hinchey 2012). The third set of avoidance techniques is management-related. The focus of these techniques is on ensuring effective documentation, cost and schedule control, quality management and constructability (Fenn *et al.* 1997; Yates and Duran 2006). Morgan (2008) recommends about thirteen such avoidance techniques. These include training of project staff, being abreast with the terms of the contract, communicating effectively on projects and ensuring compliance. The final set of avoidance techniques entails activities relating to general planning and preparation for projects (Mitropoulos and Howell 2001). The

effectiveness of these avoidance strategies can be greatly boosted if dispute causes can be sufficiently predicted at the inception of projects (Diekmann *et al.* 1994).

Some of the techniques listed under avoidance are also used for dispute management. The use of standing neutrals and negotiations are examples of such mechanisms. The idea underpinning dispute management is to ensure that festering disputes are nipped in the bud and not allowed to escalate. The current approach to dispute avoidance and management is summed up in the findings of the Dispute Prevention and Resolution Task Force of the Construction Industry Institute (CII) which recommended that parties 'start right' and 'stay right' (Vorster 1993; Diekmann and Girard 1995; Yates and Duran 2006).

The resolution mechanisms include mediation, adjudication, expert determination and arbitration. These are common among construction industry users in the United Kingdom, United States of America, Australia, Singapore and Hong Kong (Hibberd and Newman 1999; Gaitskell 2006). These options are dominant both on minor and major construction projects (Harmon 2003). The main characteristics of these dispute resolution mechanisms are well covered in the literature (Blake *et al.* 2011). Dealing with disputes in construction, thus, entails having an efficient approach to dispute avoidance, an effective dispute management strategy and a swift, cost-effective, fair and just resolution process.

Parties involved in construction dispute resolution in Ghana lacked a coherent strategy which integrated the various approaches to dispute handling into a logical process. Compared to the framework developed from the literature (see figure 1), there was a weaker emphasis on dispute avoidance and management - limited use of intermediary mechanisms. When initial efforts to resolve a dispute fail, it festers until it is eventually resolved by arbitration. Lack of coherent dispute resolution strategy is not a feature only of the Ghanaian industry – even in developed countries where much of the literature on dispute resolution processes have been developed, most parties apply the mechanisms and techniques for dispute handling disparately.

The Dispute Resolution Efficiency Cycle (DREC) is a process designed by this study to fill this gap by encouraging a holistic, integrated and context-specific approach to dispute resolution. The DREC was inductively developed based on interviews conducted and the dispute resolution literature (Mante 2014). Some key aspects of the DREC are briefly described below. Data on how to improve construction dispute resolution in Ghana were coded and concepts generated. The concepts were further categorized under four themes on the basis of the project stage at which these ideas may be properly explored and implemented (see Table 1 below).

It must be stressed that the list of concepts outlined under each of the categories developed from the data were not meant to be exhaustive. The categories were then juxtaposed with a typical project cycle in Ghana leading to the development of a four-stage construction project dispute resolution cycle called DREC. The four stages are the pre-project, dispute resolution system design, management/resolution and the post-resolution evaluation stages.

Table 1: Four Categories and their respective concepts (Source: Mante 2014)

DREC Strategies				
Categories	Context / Risks Assessment (10 Elements)	Designing the DR System (5 Elements)	Dispute Avoidance and Resolution (6 Elements)	Evaluation of Outcome-Post DR (5 Elements)
Concepts and Actions	Learning from Past experiences	Focus on agreeing a dispute resolution framework capable of delivering dispute resolution objectives of the Employer/ Contractor	Use Standing neutrals (e.g. DABs, DREs) and other ADR mechanisms to avoid and manage budding differences	Compare outcomes with Employer/ contractor's goals on dispute resolution in relation to specific project; and National policy objectives on infra-related dispute resolution
	Investigating the cost of dispute resolution			
	Need for Policy and overriding objectives for Infrastructure-related dispute resolution.			
	Considering impact of contextual factors-e.g. political interference, legal framework etc.			
	Promoting ADR use.			
	Developing standards for the use of ADR by government entities.	Aim at addressing previous dispute resolution challenges through new process	Improving project planning and management	Identifying successes - why?
	Streamlining institutional roles on infrastructure-related dispute resolution.	Identify, agree, incorporate specific mechanism to be used during the period for amicable settlement	Cutting cost of Arbitration – e.g. implementing cost sharing agreements	Identifying failures-why?
	Education and Training on relevant dispute resolution.			Making recommendations for future projects
	Setting the agenda to focus on dispute avoidance and management - Develop policy on Prevention	Training of Personnel	Instituting a forum where failures and successes of DRMs utilized will be discussed among relevant staff of Employer	
Legal reform	Setting up a Contract review unit			
Likely Outcomes	Development of Avoidance/management/resolution strategies	Incorporation of Avoidance/management/resolution strategies into Project Contract	Implementation of Avoidance/management/resolution strategies	Evaluation of Avoidance/management/resolution strategies

In effect, each of the four categories with its respective concepts/actions corresponded to one of the four elements of the DREC.

The pre-project stage covers the period between the development of the initial project brief and the procurement and tendering phase. At this stage, the Employer may focus attention on the concepts/actions outlined under the category called “*Context/Risk Assessment*”. For instance, the Employer may develop/update its overriding construction dispute resolution objective(s) at this stage. Ultimately, this was to be the starting point for the development of a project-specific avoidance, management and resolution strategy. The dispute resolution system design phase aligns with the period from the commencement of procurement and tendering through to the signing of the relevant project contract. Equipped with the ideas garnered and steps to be taken at the pre-project stage, the Employer may engage with the actions outlined under the category labelled “*designing the dispute resolution system*”. For instance, the

Employer may, at this stage, focus on negotiating a dispute resolution framework capable of delivering its dispute resolution objectives. Even where the dispute system is provided under a standard form, as is often the case with the construction industry, the Employer's team could examine critically the existing system and determine to what extent it could be modified or implemented so as to achieve efficiency within the context of the specific project.

The dispute management/resolution stage covers the construction to completion phase and aligns with the category called "*dispute avoidance and resolution*". At this stage the Employer may implement the project-specific strategies on avoidance, management and resolution. The post-dispute resolution phase spans the period immediately after the completion of the project through to the period after all or key emerging disputes have been resolved. This phase corresponds to the category labelled "*evaluation of outcome - post dispute resolution*". At this stage, the Employer may evaluate the dispute resolution strategy for the completed project. Some of the strengths of the DREC model are its ability to enhance dispute awareness, integrate dispute handling approaches, provide a context-specific strategy for dispute handling and feed-forward lessons from previous cycles.

CONCLUSIONS

Increased focus on infrastructure development as a means of achieving economic growth in developing countries has led to growth in construction activities in the public sector. As an unintended consequence, growth in construction activity has a knock-on effect on dispute emergence. The process of construction dispute resolution in Ghana, as this study found, was beset with much inefficiency. Absence of coherent dispute resolution strategy meant limited focus on dispute handling strategies other than the traditional resolution mechanisms in use which were plagued by numerous practical and contextual challenges. To deal with the problem, a modern approach focusing not merely on resolution but also avoidance and management was required. Beyond this, it was imperative that such an approach was cohesive. Not only must the dispute handling strategies be integrated but such plans must also be integrated into programmes and plans of individual parties taking into account the project context. This is where the Dispute Resolution Efficiency Cycle comes in.

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INVESTIGATING THE FACTORS INFLUENCING THE QUALITY OF ADJUDICATION OF COMPLEX PAYMENT DISPUTES IN AUSTRALIA

Samer Skaik¹, Jeremy Coggins² and Anthony Mills³

^{1 and 3}*School of Architectural and Built Environment, Deakin University, Victoria, Australia*

²*School of Natural and Built Environments, University of South Australia, Adelaide, Australia*

Statutory adjudication has been enacted throughout Australia on a state-by-state basis. The original enacting legislation may be broadly divided into two models which have become known as the East Coast and West Coast models. The East Coast model adjudication scheme – which is operational in NSW, Victoria, Queensland, Tasmania, ACT and South Australia – has in recent times come under much criticism for failing to facilitate determinations of sufficient quality with respect to large and/or complex payment claims. By carrying out a thorough desktop study approach whereby evidence is garnered from three primary sources – government commissioned consultation papers, academic publications and judicial decisions – this paper reviews this criticism and therefrom distils the key factors influencing the quality of adjudication of large and/or complex claims in Australia.

Keywords: adjudicators' determinations, complex payment disputes, security of payment, statutory adjudication.

INTRODUCTION

Statutory adjudication has been enacted progressively throughout Australia on a state-by-state basis over the past 15 years. The first Australian jurisdiction to introduce statutory adjudication was New South Wales (NSW) by virtue of the Building and Construction Industry Security of Payment Act 1999. Despite the many differences between all of the Acts in Australia, they can be broadly grouped on the basis of similarity into the East Coast model Acts (including New South Wales, Victoria, South Australia, Tasmania and Australian Capital Territory) and the West Coast model Acts (including Northern Territory and Western Australia). The East Coast model Acts were modelled after the original NSW Act and provide, in addition to an adjudication scheme, for a highly regulatory statutory payment scheme which runs alongside the contractual payment scheme. The West Coast model Acts are more akin to the UK Act, affording primacy to the contractual payment scheme. The common objective of all Acts is to facilitate timely cash flow in the construction contractual chains. The East Coast model's adjudication scheme was originally intended to assist, in particular, smaller contractors to get paid quickly (Iemma 1999: 1594) and, as such, to be a quick, informal and inexpensive process resulting in an adjudication decision provisionally binding in nature. Whilst adjudication usage rates under the East Coast model have generally been high for smaller payment claims, a significant number of large and technically and legally complex payment claims have also been the subject

¹ sskaik@deakin.edu.au

of adjudication applications. For example, in 2012/13 there were 71 adjudication determinations for payment claims \geq \$500,000 in Queensland (Qld), and 40 in NSW. For the same year, there were a further 85 adjudication determinations for payment claims between \$100,000 and \$499,999 in Qld, and 109 in NSW. This is because the eventuating scope of the legislation covered all parties carrying out construction work and/or supplying goods or services under construction contracts of all sizes. This has eventually resulted in inevitable formalisation of adjudication process, drifting away from the simple process envisaged by the Parliament. As to complexity, McDougall J has stated in *Chase Oyster Bar v Hamo Industries* [2010] NSWCA 190 at [207]-[209] that the NSW Act: “*provides a very limited time for adjudicators to make their decisions on what, experience shows, are often extremely complex claims involving very substantial volumes of documents...*”

In Western Australia (WA), where parliament aimed the legislation at the construction industry broadly rather than focussing on smaller contractors, statutory adjudication is even more frequently used to determine large payment claims. In 2013/14, 36% of the 175 adjudication determinations concerned payment claims exceeding \$500,000, with a further 35% concerning payment claims between \$100,000 and \$499,999. Indeed, the WA adjudication scheme has been so little used for smaller payment claims that this issue has been raised in the recent discussion paper for the review of the WA Act (Evans 2014: 41). Although, anecdotally, there is a general view that statutory adjudication has improved cash flow within the industry, the East Coast scheme has received a lot of criticism from practitioners for reasons relating to many procedural issues. These criticisms have, in particular, pointed at the unsuitability of the East Coast legislation in its current form to satisfactorily deal with the determination large or complex payment disputes. Notwithstanding the provisional, “*pay now, argue later*”, nature of statutory adjudication, the interim enforcement of adjudication determinations that are perceived as lacking in quality has many negative ramifications not least of which is a proliferation of judicial challenges to adjudicator’s decision which results in extra costs to disputing parties and a general undermining of faith which the construction industry has in adjudication. By contrast, the West Coast model has received little, if any, criticism in this respect, and there are minimal judicial review applications, very few of which result in the adjudicator’s decision being quashed on the basis of jurisdictional error (Marquet 2015: 8). This is not to say, however, that there is no room for improvement in the West Coast model’s approach to large and/or complex payment claims. Indeed, the recently published discussion paper for review of the WA Act sought submissions for such improvement (Evans 2014). As with the East Coast model, there is a dearth of empirical research as to the performance of the West Coast model. As such, Yung *et al.* (2015: 70) note “*the lack of appropriate evaluations of the West Coast Model.*”

This paper, written as a preliminary to inform the lead author’s PhD research, aims to identify and review the key factors that affect the perceived and actual quality of adjudication determinations. This is achieved using a desktop study approach whereby evidence is garnered from three primary sources: government commissioned consultation papers, academic publications and judicial decisions. The key factors identified will be used as the basis for survey design in a subsequent research which aims to recommend an optimal process of adjudication of large and/or complex payment claims based upon stakeholders’ views and experiences.

DEFINING LARGE AND/OR COMPLEX CLAIMS

As concluded by many authors (Australian Legislation Reform Sub-committee 2014; Wallace 2013), the “*one size fits all*” approach taken by the East Coast model legislation is no longer appropriate (if indeed it ever was) for producing quality determinations for larger and more complex payment claims. Most, if not all, of the research to date on the designing of an appropriate adjudication scheme to determine large and complex payment claims has been based on anecdotal evidence, usually in the form of submissions to government discussion papers (e.g. Wallace 2013). As such, there is a clear need for empirical research on the matter. The starting point for any such research is to determine the parameters for the large and complex payment claims to which such an adjudication scheme should apply, this section contemplates how such parameters can be defined and reviews the relevant literature to date to consider any such definitions already existing. In the search for existing definitions, the most obvious point of initial reference is the recent final report on the discussion paper into the Qld Act authored by Andrew Wallace QC (Wallace 2013), upon which the Qld Parliament based its key reform to the Act that came into effect on 15th December 2014. Based upon Wallace’s recommendations, the Qld Parliament is the first and only jurisdiction to introduce a dual adjudication scheme which provides a modified scheme to deal with what it terms ‘complex payment claims’ whilst essentially retaining its original scheme to deal with ‘standard payment claims’. For the purposes of its dual scheme, the amended Qld Act classifies all claims greater than \$750,000 as complex payment claims. Regarding his basis for choosing this amount, Wallace (2013:183) comments: *“The value of this monetary limit is also likely to be a source of great debate. Whilst I am not particularly wedded to the sum, I have concluded that it is appropriate to tie the monetary limit to that of the civil jurisdiction of the District Court of Queensland, which is currently set at \$750,000. Some will argue this figure is set too high, whilst others will argue it is too low. For claims in excess of this amount, i.e. \$750,001 the parties are likely to be legally represented and I therefore assume well able to navigate the proposed legislative paradigm.”*

Notably, however, Parliament adjusted the definition of complex claims recommended by Wallace, who originally classified complex claims as claims above \$750,000 or any claims on the basis of time-related or latent condition cost. Upon further investigation, the Parliamentary Committee (2014) set up to examine and report on the reform Bill advised against accepting Wallace’s inclusion of claims on the basis of time-related or latent condition cost. This advice was based upon concerns about the ambiguity and potential for confusion amongst contractors with respect to the meaning of latent condition and time-related costs, as well as the potential for these types of costs to have a broad scope of application meaning that even some simple claims (e.g., based on time sheet day work or discovery of hard rock during excavation) could be considered as complex claims (Queensland Parliamentary Committee 2014: 20). The Qld experience brings to light the question as to whether it is possible for the legislation to clearly define a claim with respect to its nature of complexity for the purposes of adjudication. This is a question that the proposed empirical research should seek to address by, it is suggested, diagnosing the nature of claims further and relating them to the required skills and powers of adjudicators as well as the timeframes governing proceedings. An alternative to define criteria for claim complexity could be to leave the decision as to claim complexity (and, thus, adjudication scheme) up to the body appointing the adjudicator. Again, the ramifications of this suggestion would need further empirical investigation. If the

nature of the claim is taken out of any definition (as happened in Qld), large and complex claims would be defined by a monetary amount alone. A large claim per se does not, of course, necessarily reflect complexity in the submission as some large claims are straight forward calculations of the quantity and amount of executed works. However, generally speaking, larger claims are more likely to involve complex legal issues and, even if they don't, will have more volume of submissions for the adjudicator to consider. As Yung *et al.* (2015: 61) found in their survey of 22 adjudicators in WA, while larger claims are not by virtue more complex, they have a greater potential to involve complex points of law. Thus, it may be valid to define complexity of claims for the purpose of a dual adjudication scheme according to solely amount. Notably, the English High Court in *CIB Properties Limited v Birse Construction* [2004] EWHC 2365 preferred that the suitability of a matter for adjudication not be assessed on whether it was too complicated, but whether the adjudicator was able to reach a fair decision within the timetable.

Looking elsewhere for indicators of claim complexity in relation to adjudication, the Victorian Act (s 10(b)) excludes many types of payment claims with likely complexity from being adjudicated including claims for certain disputed variations, damages under or in connection with the contract, time-related costs, latent conditions or changes in regulatory requirements. Such exclusions indicate that the Victorian Parliament did not regard the 'one size fits all' East Coast model adjudication scheme appropriate for complex claims. This raft of exclusions, however, has been blamed for adding to the complexity of the Victorian Act itself, resulting in a low adjudication usage rate (Shnookal 2009:9). The WA Act (s 31(ii)(iv)) provides that an adjudicator must dismiss an adjudication application without making a determination of its merits if satisfied that it is not possible to fairly make a determination because of the complexity of the referred matter. Thus, in WA, Parliament is content to leave the decision about complexity of a payment claim up to the adjudicator, although the judiciary has required that an adjudicator must provide adequate reasons for dismissal due to complexity and has commented "*upon the need for adjudicators not to too readily form a view that a matter is too complex to be fairly determined.*" (See *Silent Vector Pty Ltd T/as Sizer Builders and Squarcini* [2008] WASAT 39).

KEY FACTORS IMPACTING ADJUDICATION QUALITY

Before discussing the key factors affecting adjudication quality, it is necessary to briefly consider what is meant by adjudication quality. The ultimate yardstick by which adjudication quality can be measured is to be found in the legal accuracy – both in terms of procedural and substantive fairness – of adjudicators' determinations. However, recognising that there is a trade-off between fairness and efficiency in dispute resolution (Susskind and Cruikshank 1987: 21-33), this criterion needs to be calibrated in the light of the legislative objective, being to provide a rapid dispute resolution procedure in order to expedite cash flow on construction contracts. Thus, it would clearly be absurd to hold adjudication determinations up to as higher level of scrutiny as in arbitration or litigation. On the other hand, there surely must be a quality 'floor' below which determination quality must not fall otherwise the overemphasis on efficiency in lieu of justice would result in a process that the parties would perceive as unfair with the consequence that they are more likely to seek to undermine it (Susskind and Cruikshank 1987: 21-33; Gerber and Ong 2013: 332). In the context of adjudication, it is proposed that an adequate level of quality be defined in terms of adjudicators' determinations that meet the basic and substantial requirements of a satisfactory dispute resolution system, namely that: adjudicators act within their

legislative jurisdiction; the key elements of natural justice, or procedural justice, are afforded; adjudicators make a good faith attempt to exercise their powers under the legislation; and adjudicators' determinations are free from gross non-judicial errors of law that materially and substantially affect the determination. A review of the relevant literature identifies the following five key factors that impact upon adjudication quality as defined above: adjudicator appointment, regulation of adjudicators, reviewability of adjudicators' determinations, timeframes in the adjudication process, and adjudicators' powers. These factors are discussed in more detail below.

Adjudicator Appointment

The way in which an adjudicator is appointed may have a direct bearing on the quality of the outcome. The appointment of adjudicators by authorised nominating authorities (ANAs) under the East Coast model has been much criticised for its leading to: perceptions that profit-driven ANAs are biased towards claimants (Wallace 2013: 131-145; Collins 2012: 72), allegations of adjudicator shopping whereby a claimant or its representative demands that an ANA either appoint or not appoint certain adjudicators, otherwise the claimant would refer its adjudication application to another ANA (Wallace 2013: 140), and accusations that some ANAs maintain an unhealthy relationship with claims preparers, whereby preparers are recommended to claimants by an ANA with the expectation that the preparer will direct the adjudication application to the ANA (Wallace 2013: 134, 148-150) or in expectation of receiving future appointments as an adjudicator from the ANA (Wallace 2013: 145). Such matters clearly contravene one of the fundamental tenets of natural justice, that the decision-maker conducts themselves in a manner free from actual or apprehended bias. Accordingly, the recent reform of the Qld Act abolished appointment by ANAs replacing it with appointment by a single government registry within the Queensland Building and Construction Commission.

Regulation of Adjudicators

Regulation of adjudicators may impact adjudication quality in terms of adjudicator eligibility, training and the ongoing monitoring of adjudicator performance. The importance of setting appropriate criteria for eligibility and training is clear, directly impacting upon the ability of an adjudicator to both run the adjudication process in a procedurally fair manner as well as having the requisite knowledge and experience to arrive at an appropriately just and accurate determination. Zhang (2009) noted that the risk of injustice in rapid adjudication requires a high standard of adjudicator's expertise. The regulation of adjudicators varies widely from State to State, with regulations being generally quite relaxed. With the exception of Qld (See Building and Construction Industry Payments Regulations 2004 (Qld, S2A), the regulations governing the eligibility, registration and performance of adjudicators under the East Coast model appear to be wanting. The NSW legislation, for instance, requires adjudicators to have such qualifications, expertise and experience to be eligible to perform adjudication but no relevant regulations listing such have ever been made. In practice, therefore, it is left to the ANAs to ensure adjudicators are suitably qualified, trained and experienced. In the absence of formal criteria regarding adjudicator appointment, it is also possible for ANAs to select an adjudicator based upon availability rather than experience and qualifications in order to meet the strict time limits. Accordingly, Wallace (2013:230) notes, "*adjudicators accept appointment by an ANA at a time when they have little or no knowledge of the issues in dispute...*" To

compound matters, the East Coast legislation provides no deterrent against adjudicators accepting adjudication appointments that they feel unqualified to properly determine with the exception of the Qld Act (s 35(6)) which deprives an adjudicator of his or her fees where a determination has been set aside for want of good faith. In his PhD thesis, Munaaim (2012) conducted interviews with highly experienced lawyers in NSW who expressed their dissatisfaction with the quality of adjudicators. Munaaim found that ANAs in NSW do not have similar quality control over adjudicators and their training courses significantly vary. He added that some ANAs provide training for months whilst other provide only a few days. South Australia is an anomaly amongst the East Coast legislation having set compulsory minimum requirements for an adjudicator to be eligible to practice². However, these regulations do not mention any requirements for legal qualifications for adjudicators dealing with complex claims which may require application of complicated legal principles to complex facts. As Wallace (2013: 230) observes, “*adjudicators are often called upon to consider complex areas of building and contract law, yet they are not required to be legally qualified.*” It is likely that one of the reasons for the recent high rate of adjudication determinations that have been quashed by the courts under the East Coast model is linked to shortcomings in the way adjudicators are regulated. As stated by the Australian Legislation Reform Sub-committee (2014: 38), “*the courts have seen more and more cases where the quality of the adjudication decision making process has been so poor that the courts have been increasingly willing to intervene.*” In WA, although the regulations prescribe certain eligibility criteria, legal qualifications are not required. Noting this, Yung *et al.* (2015: 71) recommend that legal training should be required as “*73 per cent of adjudicators in Western Australia are not legally trained but quite a number of claims have been prepared by lawyers and included detailed legal submissions.*”

Reviewability of adjudicators’ determinations

Adjudication, with its abbreviated timeframes, has always been acknowledged as a somewhat “*rough and ready*” dispute resolution process. As such, Australian courts (as well as their English counterparts) have generally been happy to uphold adjudicator’s decisions containing non-jurisdictional errors of law, only quashing those where adjudicators have strayed outside the boundaries of their jurisdiction. In its 2004 decision in Brodyn³, the NSW Court of Appeal restricted the grounds to quash an adjudicator’s determination even further to a failure to comply with five basic and essential requirements of the Act, where substantial breaches of natural justice have occurred and the adjudicator has failed to exercise their powers under the Act in good faith. Although jurisdictional error (with relief in the form of prerogative writs) has since been reinstated as the basis for judicial review in NSW⁴ and Victoria⁵, the courts have shown little appetite to broaden the opportunities for challenges to adjudication determinations beyond Brodyn. Consequently, as long as an adjudicator has been duly appointed in accordance with the Act’s mechanisms and has addressed the correct issues in dispute, it will be very difficult for a disgruntled party to have the adjudicator’s determination quashed in court even where the adjudicator has determined the issues in the wrong way. Thus, there are several instances where adjudicators’ determinations containing errors of law on the face of the record that

² See s 6, Building and Construction Industry Security of Payment Regulations 2011 (SA).

³ Brodyn Pty t/as Time Cost and Quality v Davenport and Anor [2004] NSWCA 394 at [52]-[53]

⁴ Chase Oyster Bar v Hamo Industries [2010] NSWCA 190

⁵ Grocon Constructors v Planit Cocciardi Joint Venture [No 2] [2009] VSC 426

materially and substantially affect the adjudication outcome have been upheld by the courts⁶. In other words, in striking a balance between justice and efficiency, the courts for now appear to be prepared to allow errors of law on the face of the record in order to support the statutory adjudication process.

Whilst the courts do not view significant errors of law on the face of the record as sufficient to invalidate adjudicators' determinations, this doesn't mean they should be discounted as an indicator of adjudication quality. Indeed, it is argued that an optimal adjudication scheme should strive to encourage as much legal accuracy as is possible in determinations within the designated timeframes. The minimisation of errors of law has a direct bearing on stakeholders' confidence in the adjudication process. The more legally accurate an adjudicator's determination, the less likely it is for a losing party to either search for grounds upon which to challenge the determination, or to subsequently pursue the claim for a final binding decision in arbitration or litigation. The potential for adjudication to reduce overall disputing costs to the construction industry should not be understated, and the failure of parties to accept an adjudicator's determination as a final resolution should be seen as a lost opportunity to reduce disputing costs. Indeed it was in this context that statutory adjudication had its roots in the UK and subsequently appears to have precipitated a significant decrease in the amount of UK construction litigation (Davenport 2007: 13). Aside from judicial review, there are limited rights to adjudication review provided for in the Victorian, ACT and West Coast model Acts. In the Victorian Act (s 28(b)), adjudication determinations may be subject to review on the basis that the determination exceeds \$100,000 and includes 'excluded amounts'. The review is carried out by a second adjudicator appointed by the ANA. Under the ACT Act (s 43(2)), an appeal may be made to the Supreme Court on any question of law arising out of an adjudication decision subject to certain conditions being satisfied. The WA (s 46) and NT (s 48) Acts allows a review of an adjudicator's decision by the WA State Administrative Tribunal (WASAT) or Local Court (NT) to dismiss an adjudication application without making a determination of its merits. Since the commencement of the WA Act to 30 June 2014, there have been 33 review applications to WASAT, 10 of which set aside the adjudicator's decision to dismiss.

Notwithstanding these limited avenues of review, it is argued that the general absence of any mechanism by which to review the merits of an adjudicator's determination made within jurisdiction directly impacts upon the quality of adjudication determinations. An optimal adjudication process should maximise, within the legislative objective of expediency, the opportunity that adjudicators' determinations are made in accordance with the correct and relevant law. In the immediate wake of Brodyn, Murray (2006) viewed that the challenge to uphold the integrity of the adjudication regime now fell to government and industry by implementing the necessary systems and procedures to ensure that adjudication determinations are of the highest possible standard. In order to achieve such quality control, it is proposed that a swift system of review provided for within the legislation is needed. Marquet (2015: 15) has suggested that the merits review avenues available under the West Coast model are likely to be more appropriate than judicial review proceedings, although adding that further investigation into the frequency, duration and cost of merit review applications under the West Coast legislation is necessary before it can be said with certainty that the merit review model produces better overall outcomes (Marquet

⁶ See, for example, *Clyde Bergemann v Varley Power* [2011] NSWSC 1039; *New South Wales Land and Housing v Clarendon Homes* [2012] NSWSC 333; *Uniting Church in Australia Property Trust (Qld) v Davenport and Anor* [2009] QSC 134

2015: 16). Notably, the Singaporean Act (s 18) provides a wider merits review system which, it is proposed, could be considered for adoption into the Australian legislation.

Timeframes

As previously mentioned, in dispute resolution there is a trade-off between justice and efficiency. An optimal adjudication scheme for large and/or complex claims, therefore, needs to set a timetable which allows sufficient time to meet the basic and substantial requirements of a satisfactory dispute resolution system. There is no doubt that the ‘one size fits all’ timeframes prescribed by both the East and West Coast models are expeditious when compared with the international legislation. For example, whilst the East Coast model allows 10 business days, and the West Coast model 14 days, for an adjudicator to make his or her determination (with the exception of the recently amended Qld Act which now allows adjudicators up to 20 business days to issue decisions on complex claims), their counterpart has 45 working days to do so in Malaysia and 28 days to do so in Ireland and the UK. Jacobs (2014: xi) comments, “[u]nfairness may arise, where large complex claims are submitted to the lay adjudicator for determination within the “pressure-cooker” time limits set by the relevant [Australian] Acts”. Accordingly, in the recent discussion paper for review of the WA Act, the issues of whether the timelines for respondents to serve their written adjudication response and for adjudicators to make their decisions should be extended have been raised (Evans 2014: 40-41).

Whilst the East Coast model timeframes may be appropriate for smaller straightforward payment claims, there is mounting evidence – in the form of adjudicators’ determinations being quashed by the courts for substantial denial of natural justice⁷ and/or failure to exercise their power in good faith⁸ – to suggest they are inadequate to afford adjudicators enough time to meet the key requirements for a fair determination. Accordingly, Marquet (2015) states that, inter alia, the strict time bars have led to a substantial increase in the judicial review of adjudication determinations. The adjudicator’s task has been made all the more difficult by the formalisation of the adjudication process that has occurred for large and complex payment claims with parties typically engage lawyers to prepare their adjudication applications and responses, and often submitting copious amounts of documentation – including statutory declarations, legal submissions, delay analyses, site inspections, photographs and technical expert reports – to support their cases. Given the East Coast model’s requirement for an adjudicator to ‘consider’⁹ all duly made submissions and to make this apparent in his reasoning (See *Laing O’Rourke Australia Construction v H&M Engineering and Construction* [2010] NSWSC 818 at [73]), the adjudicator is faced with a very challenging task. This was acknowledged by the court in *Laing O’Rourke* as follows: *“I accept, too, that the adjudicator was required to assimilate a huge mass of material and to deal with it, to the extent of producing a reasoned conclusion, in a very short space of time. But even allowing for those matters, it is in my view clear, when this aspect of the determination is considered as a whole ..., that the adjudicator did not turn his mind to, and thus did not consider, those features of LORAC’s defence that I have mentioned.”*

⁷ See *Metacorp Australia Pty Ltd v Andeco Construction Group Pty Ltd and Ors* (No 2) [2010] VSC 255; *St Hilliers Contracting Pty Limited v Dualcorp Civil Pty Ltd* [2010] NSWSC 1468; *Watpac Constructions v Austin Corp* [2010] NSWSC 168.

⁸ See *Laing O’Rourke Australia Construction v H&M Engineering and Construction* [2010] NSWSC 818; *Lanskey v Noxequin* [2005] NSWSC 963; *Holmwood Holdings Pty Ltd v Halkat Electrical Contractors Pty Ltd and Anor* [2005] NSWSC 1129

⁹ The word ‘consider’ interpreted by the courts in *Tickner v Chapman* [1995] FCA 1726 at [39] to mean an ‘active process of intellectual engagement’

There is a limit to how much material a single adjudicator can intellectually engage with in just 10 business days, and the overwhelming of an adjudicator by sheer volume of paperwork may, it seems, be likely to leave the door ajar for a potential judicial challenge on the grounds of breach of natural justice and/or want of good faith. In addition to the formalisation of the adjudication process for large and/or complex claims, the long running practice of claimant's launching 'ambush' claims clearly poses a threat to quality of the adjudication determination (See, for example, *Dorchester Hotel Ltd v Vivid Interiors Ltd* [2009] EWHC 70). Ambush claims are facilitated by the East Coast model Acts allowing a claimant to spend several months preparing a comprehensive and lengthy payment claim for a substantial monetary amount, leaving the unsuspecting respondent only ten business days to respond in its payment schedule and five business days to prepare its adjudication response. Notably, in the recent reform of the Qld Act, these timeframes have been extended for complex claims based on when the adjudication application was made with regard to reference date. As well as being procedurally unfair, ambush claims typically will require an adjudicator to consider a huge amount of submissions in an insufficient timeframe, presenting a very real risk of the door being left ajar for a judicial challenge for breach of natural justice or want of good faith. Yung *et al.* (2015: 64) found in their survey of 22 WA adjudicators that ambush claims are not a concern under the West Coast model as there is a 28-day timeline for starting an adjudication.

Adjudicator's Powers

Whilst the West Coast model encourages adjudicators to be evaluative (WA Act, s 32(1)(b) and NT Act, s34(1)(b)), the East Coast model Acts impose many restrictions on the way in which adjudicators make their determinations. Under the East Coast model, adjudicators are limited to a consideration of the Act and documents submitted by the parties. Such a restrictive approach has the potential to negatively impact upon the quality of adjudicators' determinations. As Gerber and Ong (2013: [16.48] to [16.50]) state: "*An active, inquisitorial approach to adjudication therefore allows the merits of the dispute to be fully investigated, and is said to result in a more reasoned and accurate determination... it is clear that a passive, 'rubber stamp' approach [referring to the East Coast model] to adjudication is not conducive to the final and just determination of a dispute.*" (Emphasis added). Both East and West Coast models give the adjudicator the authority to request further submissions from the parties, and to call informal conferences with the parties although they are silent on how such conferences should be conducted. Unlike the East Coast model, however, the West Coast model allows legal representation in conferences and allows the adjudicator to engage an expert or arrange for testing unless all parties object.

CONCLUSION AND FURTHER RESEARCH

Despite its high usage rate in NSW and Qld, and general agreement that it has helped to expedite cash flow in the construction industry, the Australian East Coast model statutory adjudication scheme has come under staunch criticism for not being able to deliver quality adjudication determinations for large and/or complex payment disputes. In order to stem the increasing rate of adjudicators' determinations quashed by the courts, sustain the construction industry's confidence in the adjudication scheme, and to benefit from the reduction in disputing costs that quality adjudication determinations have the potential to bring to the construction industry, a modified adjudication scheme is needed designed specifically to cater for the challenges of large and/or complex payment disputes. This has been recognised by the Qld

Parliament, which has been the first and only Parliament to reform its Act to provide for a dual scheme of adjudication. Notwithstanding the Qld reform, a review of the relevant literature reveals that there appears to be a dearth of empirical research informing the design of an appropriate adjudication scheme for large and/or complex payment claims in either the East or West Coast model legislation. As a preliminary to embarking upon this path of empirical research, this paper has identified and briefly discussed from the relevant law and literature five key factors that influence the quality of adjudicators' determinations, namely: adjudicator appointment, regulation of adjudicators, reviewability of adjudicators' determinations, timeframes in the adjudication process, and adjudicators' powers. Moving forward, it is now the intention of the lead author to design research surveys based upon these factors with the ultimate objective of formulating a roadmap with recommendations that may be applied to help optimise the various Australian adjudication schemes for the determination of large and/or complex payment disputes.

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A PROPOSED ROADMAP TO OPTIMISE THE ADJUDICATION OF COMPLEX PAYMENT DISPUTES IN AUSTRALIA

Samer Skaik¹, Jeremy Coggins² and Anthony Mills³

^{1 and 3}*School of Architectural and Built Environment, Deakin University, Victoria, Australia*

²*School of Natural and Built Environments, University of South Australia, Adelaide, Australia*

In Australia, statutory construction adjudication has recently received a lot of criticism due to the increasing amount of determinations that have been quashed upon judicial review, and anecdotal evidence from some quarters showing dissatisfaction with the quality of adjudication decisions. Such criticism is particularly aimed at adjudications of large and technically and legally complex payment disputes, where adjudicators are under pressure to consider substantial volumes of submissions in very tight timeframes. More specifically, criticisms have been directed at, inter alia, adjudicator's regulations, procedural fairness, jurisdictional powers and finality of decisions. This paper reviews the measures to improve the quality of adjudications of complex payment disputes then proposes a roadmap by selecting the Qld model as a benchmark but suggesting further improvements identified and explained via specific steps or pit stops. The pit stops include criteria for timeframes of complex claims, appointment, regulation and powers of adjudicators and a review system on the merits to control the quality of adjudication decisions replicating the Singapore model. The findings remain as blunt instruments and deemed as hypotheses to inform subsequent empirical research which the authors are currently undertaking to further investigate, strengthen and validate the findings of this study in order to propose a reliable and useful guide to any parliament seeking to optimise its statutory adjudication to effectively deal with complex payment disputes.

Keywords: adjudicator's decision, complex disputes, large claims, security of payment, statutory adjudication.

INTRODUCTION

The Australian Security of Payment (SOP) regime was enacted first in NSW fifteen years ago, then all other states have enacted their own legislation. The East Coast states have followed NSW model with some modifications, while the West Coast states substantially followed the UK and NZ models. The common objective of all legislations was to protect vulnerable firms by giving them statutory rights to receive payment for the executed works through rapid, informal and inexpensive Adjudication. The steady increasing size and complexity of adjudicated disputes in Australia uncovered many shortcomings in the legislation operation in dealing with such types of disputes, which resulted in steadily losing confidence in the regime. Moreover, SOP has recently received a lot of criticism due to the increasing number of determinations that have been quashed upon judicial review, and anecdotal evidence showing dissatisfaction with the quality of adjudication decisions. Such

¹ sskaik@deakin.edu.au

criticism is particularly aimed at adjudications of large, technically and legally complex disputes, where adjudicators are ill equipped to resolve them fairly.

The growing dissatisfaction with adjudicator's determination is obvious with a large volume of case law regarding challenged adjudications in courts as reported by Australian Legislation Reform Sub-Committee (ALRS 2014). This unsatisfactory situation urged many legal academics and practitioners to debate how an effective statutory adjudication regime should look like in response to the evolving criticism. This paper is deemed to contribute to this debate drawing upon relative previous work from a different perspective starting with reviewing the requirements of effective dispute resolution platform and aiming to propose a roadmap to optimize adjudication of complex payment disputes in Australia.

EFFECTIVE BINDING DISPUTE RESOLUTION

Parties to any construction dispute seek to have their dispute fully sorted out in a quick, inexpensive and informal manner. Not only does a builder seek to recover disputed progress payments from his employer but he is also desperate to have all current disputes resolved to ensure certainty in business. Gerber and Ong (2013) determined three key essential requirements for an effective binding dispute resolution, namely, procedural fairness, accessibility and finality. Yung *et al.* (2015) set four measures of the effectiveness stemmed from the objective of the WA Act: fairness, speed, cost effectiveness and informality. These measures are discussed briefly below.

Procedural Fairness

Procedural fairness may include the impartiality and independence of the decision maker as well as affording both parties the right to present their defensive arguments and be fairly heard. The parties should feel that their arguments have been considered and should receive a reasonable reasoned conclusion to understand the grounds on why they have won or lost. The selection and appointment of a qualified decision maker and the assurance that he is properly equipped with the necessary powers to perform his functions are key integrated features for the parties to believe that prospective justice will be achieved. Nevertheless, the more procedural fairness is considered in dispute resolution, the more expensive and lengthy it becomes (Gerber and Ong 2013). The challenge for any decision maker is how to strike the balance of allowing fair hearing while upholding economic and speedy dispute resolution processes.

Accessibility (Speed and Cost Effectiveness)

According to Gerber and Ong (2013), the speed and affordability of a dispute resolution process are the main characteristics of any accessible justice system. The inherent cost in the lengthy process, including legal fees and case administration, is a major barrier that may force desperate disputants to seek alternative ways to get their dispute settled. Some parties cannot afford lengthy proceedings of dispute resolution as it may lead to injustice where a crucial evidence, that a party relies on, may be no longer available.

Finality

Finality embraces not only the extent in which a disputant can appeal a binding decision but also the limitations on his rights to commence a second proceeding on the same dispute after obtaining the decision on the first dispute (Gerber and Ong 2013).

Arbitration provides a greater certainty on the finality of the outcome due to the very limited grounds of appeal. Although Statutory Adjudication is an interim process that does not prevent any party to commence other legal proceedings, it offers a “*temporary final*” and binding determination with very limited grounds of appeal. However, the strict limitations to challenge some decisions, that contain an error of law or technical errors, may leave the aggrieved party without a quick remedy against unjust decision.

Informality

Yung *et al.* (2015) mentioned three factors that compromise informality: standardized structure of proceedings, abidance by rules of evidence and engagement of expert witness and lawyers. They also found that informality does not generally have an impact on accuracy of determination under the West Coast model. Since they help understand the tenets behind the evolution of statutory adjudication, the above measures stand as good criteria to evaluate and improve existing SOP legislation as follows in the next sections.

THE EVOLUTION OF AUSTRALIAN LEGISLATION

East Coast model

For the last fifteen years, the leading NSW legislation has been prone to various governmental reviews aiming to improve its operation against the set objectives. In 2004, NSW Department of Commerce released a review report mentioning many suggestions to improve the legislation including but not limited to have minimum qualifications for adjudicators and allow longer duration for adjudication determination. Six years later, the Department of Services Technology and Administration (2010) released a discussion paper drawing upon the above report proposing significant improvement to NSW Act aiming to increase confidence in the regime and adding certainty to the outcome of adjudicator’s determination. The paper addressed serious concerns regarding the need for better regulation of adjudicators and the capacity for the Act to deal with complex claims, especially in high value contracts, in which the risk and impact of incorrect adjudication is severe. In 2012, Bruce Collin QC was assigned by NSW Government to prepare an independent report on the construction industry insolvency. Collin’s final report addressed various recommendations to improve the NSW Act to give better protection to subcontractors (Collins 2012). The report endorsed collective submissions from the industry proposing to allow a sliding scale of timeframes based on the size of adjudicated claim, so the larger the claim, the more duration is given to respondents and adjudicators. The report also recommended a specific training system for adjudicators and proposed core topics to be covered in the training course. After all, the three amendments of NSW legislation enacted in 2002, 2010 and 2013 did not implement any of the recommendations concerning large or complex claims.

In Victoria, the SOP regime was amended in 2006 (Section 10b) to prevent claims involving complex matters such as latent conditions and time related cost from being adjudicated. South Australia released final report of discussion paper in May 2015 stating that most of received submissions from the industry favoured the Qld model in its new form and putting recommendations to effectively deal with complex claims such as longer timeframes and better appointment process of competent adjudicators (Moss 2015).

Queensland model

Wallace (2013) released his final report, which reviewed the operation of the Qld Act. Accordingly, the Act was substantially amended in December 2014 introducing exceptional revolution in adjudication proceedings establishing, inter alia, a dual scheme that provides different mechanisms in dealing with standard and complex payment claims on the basis of the claim monetary value. The timeframes are kept the same for standard payment claims except for the respondent, who can make the adjudication response within 10 days instead of 5 days in the original Act². For complex payment claims, the respondent now has 15 business days to submit his adjudication response³ and can raise new reasons that were never addressed in the payment schedule⁴. He is also eligible to apply to the adjudicator for an extension of time of up to 15 business days to submit his response⁵. These arrangements were sought to overcome the criticisms of ambush practice and lack of procedural fairness. The adjudicator can have up to 20 business days to issue decision instead of 10 days stated in the Original Act.⁶ As proposed by Wallace, the claim monetary value was fixed at \$ 750,000, so any claim greater than this value will be treated as a complex claim even though it involves simple matters. Wallace simply adopted this cap to tie it with the monetary limit of the civil jurisdiction of the District Court of Queensland. According to the statistics, he assumed that approximately 90% of claims will be adjudicated under the standard scheme.

On the other hand, the Reform established robust arrangement for appointment and regulation of adjudicators. The Reform not only abolished Authorised Nominating authorities⁷ replacing it with a single governmental registry in response to perceived bias in adjudicator's appointment, but also established a unique Policy for adjudicator grading and selection criteria.⁸ The Policy established, inter alia, a grading scale for adjudicators depending on their qualifications, experience and skills, namely, Adjudicator (lowest), Advanced Adjudicators and Senior Adjudicator (highest), whereas complex or large claims cases are only assigned to senior adjudicators. The policy states that: "*The Registrar will have discretion when assessing an application to nominate a Senior Adjudicator irrespective of the claim value where the complexity of the matters in dispute warrants nomination of a Senior Adjudicator.*"

West Coast model

Until now, there have been no appropriate studies on the performance of the West Coast model with regard to its capacity to deal with complex claims. However, many academics trust this model being more effective than the East Coast model. The model applies the approach of "*one size fits all*" where adjudication proceedings are the same no matter how simple or complex is the claim allowing only 14 days for adjudicator to issue determination. Also, the legislation does not have adequate regulations governing the appointment and regulation of adjudicators. The Report of ALRS (2014) recommended a national scheme across Australia which draws heavily from the West Coast model. However, the ALRS Report embraced the need of quality control system of adjudicators as well as sliding timescale for determinations (ALRS 2014: 63 and 65). Yung *et al.* (2015), argued that it may be too early to discuss

² S 24A (2) a, Qld Act.

³ S 24A (4), Qld Act.

⁴ S 24 (5), Qld Act.

⁵ S 24 A(5), Qld Act

⁶ S 25A (5&6), 25B; Qld Act.

⁷ S 114, Qld Act.

⁸ See Adjudicator Grading and Selection Criteria for Nomination of Adjudicators 2014 Policy.

harmonized national scheme while there is a very little and unreliable research evaluating the effectiveness of the West Coast model. Evans (2014) issued a discussion paper endorsed by the Building Commissioner in an attempt to review the performance and operation of the Western Australia legislation since its commencement. The paper suggested important inquiries to the industry pertaining the appropriate time limits for complex claims as well as regulation of adjudicators including qualifications, registration, auditing and training. Until the time of writing this paper, the final report was not released.

THE ROADMAP TO EFFECTIVE ADJUDICATION REFORM

Marquet (2015) confirmed the need for reform noting that the current volume of judicial review is destructive of speed, certainty and affordability. He also noted that the improvement of SOP regimes requires the achievement of just outcomes, not merely fast or cheap ones. Having summarised the key developments and proposals to date with respect to the various Australian legislation, this paper now turns its attention to the future by proposing a roadmap towards the destination of optimising the statutory adjudication of complex payment disputes in Australia. This roadmap starts from a well-established position based upon the government and academic literature to date, the shortcomings of the existing East and West Coast model adjudication schemes, and consequent need for a better designed adjudication scheme to determine complex payment disputes. As such, rather than retracing the need for an improved adjudication scheme, the roadmap aims to move forward the research by identifying five key areas (or pit stops) from the relevant literature where it is contended that empirical research is now needed in order to realise the destination of an optimal adjudication scheme for complex payment claims. The key research areas – selection of Qld model as a benchmark, criteria of complex disputes timeframes, appointment and regulation of adjudicators, powers of adjudicators and merits review system– are discussed below. The discussion includes a justification of each issue as a research area, and an exploration of the various options available to address the issues sometimes even putting forward hypotheses for the research. At this preliminary stage, this roadmap represents somewhat of a ‘blunt instrument’, and intended to proffer an ‘aunt Sally’ for feedback in order that the roadmap be refined for subsequent use by the lead author as the basis for his PhD research.

Queensland Model as a Benchmark

It does not make sense to reinvent the wheel and leave the efforts of other legislatures and scholars behind. As a start point of the roadmap, the Authors are of the opinion that the Qld model is deemed the most appropriate benchmark to deal with complex payment disputes because of the reasons mentioned earlier such as the appointment process of adjudicators and the new mechanism to deal with complex claims. Having said that, it may be too early to judge the effectiveness of the Qld model, so a case study will be undertaken to evaluate the performance of the Act in its recent form to have certainty of the improved outcome. Also, there is still a great opportunity to build upon the current features of Qld model and enhance certain areas relating to complex claims by considering the remaining pit stops down the road as follows next.

Criteria of Complex Disputes Timeframes

Since SOP was successful in dealing with simple and small claims, it is quite important to maintain such strength and draw the line, so complex claims can have a different process within the legislation. Table (1) below shows the distribution of large claims in major Australian States. As part of the proposed measures in this study, the

cap of complex claims should be reduced to \$500,000 instead of \$750,000 which will capture a bit more applications of likely complex nature (e.g. 3% more as in Qld) and tie it with the claims categorizing of annual reports for accessible data monitoring. This monetary value is distilled from the NSW Home Building Act, which limits the jurisdiction of Tribunal to review building disputes up to \$500,000,⁹ otherwise, the claim should be dealt with by a district court or a supreme court. This limitation of jurisdiction reflects the nature of complexity and substantial economic substance of claims exceeding this amount. Also, a sliding scale of time limits should be developed for claims larger than \$500,000, so the larger the claim, the longer the timeframe of adjudication decision to avoid the pitfall of “one size fits all” approach. A nice proposal of such sliding scale has been already developed by ALRS (2014: 65) and deemed a good start point of research to establish reliable and deliberate time limits.

Table 1: Distribution of large adjudicated claims in Australia¹⁰

Claim amount	NSW			QLD			WA		
	2012	2013	2014	2012	2013	2014	2012	2013	2014
Years	2012	2013	2014	2012	2013	2014	2012	2013	2014
< 100,000	73%	78%	74%	78%	71%	73%	49%	44%	29%
100-499,000	20%	16%	22%	11%	16%	14%	32%	25%	35%
≥ 500,000	7%	6%	4%	11%	13%	13%	19%	31%	36%

Furthermore, complex claims should include smaller claims with a defined cap between \$100,000 and \$500,000 but this consideration should be only decided by the Registrar following the complexity criteria explained below. The minimum proposed threshold of \$100,000 ensures that more than 70% of applications will be adjudicated under the original scheme. Also, Department of Services Technology and Administration (2010) considers simple claims lower than \$100,000. This threshold replicates the same limits in Victoria for having adjudication determination reviewed.¹¹ According to his second reading speech, his Honour Madden (2006) confirmed that such limit is given in order not “to disadvantage small subcontractors who rely on prompt payment to stay in business”. This proposal will ensure that considerable percentage of subcontractors’ claims of complex nature against head contractors will be likely dealt with, in similar fairer proceedings to the corresponding claims served by head contractors against their own principals. The complexity criteria for claims ranging from \$ 100,000 to \$500,000 should include the volume and nature of documents, inclusion of expert reports, the nature of disputed matters such as damages, breach of contract, prolongation claims, legal matters, latent conditions, changes in regulations etc. Ultimately, the above proposed thresholds and criteria of complex claims will be subject to further consultation with the industry stakeholders.

Appointment and Regulation of Adjudicators

Although the Qld Reform replacing ANAs with a single governmental registry was necessary to remove the apprehended bias, it does not appear to resolve the problem of bias where Qld Government is part of adjudication. This issue was highlighted by the Parliamentary Committee (2014) who suggested to seek an alternative to the new appointment process should the Government becomes involved in Adjudication. Such alternative might be naming one of the reputed abolished ANAs such as IAMA in the relevant regulation for this purpose. The Qld Policy for selecting and grading

⁹ See s 48K of Home Building Act 1989 - NSW

¹⁰ Note: In the annual reports, WA adopts calendar year while NSW and Qld adopts financial year. Also, for 2013, the table considered the first two quarters to work out the NSW percentage which might change upon the release of the annual report.

¹¹ See s 28A (a) of Vic Act.

adjudicators¹² is an excellent tool but needs further pragmatic improvement to increase the quality standards of adjudicators dealing with complex claims. For instance, the Registrar, once receives both adjudication application and relevant response, should decide the time limits of adjudication decision based on the size and/or complexity of claim in accordance with the above criteria as soon as possible. Then, the Registrar can refer the case to a prospective adjudicator with a copy to both parties stating whether the claim is simple or complex and fix the relevant time limits in the referral notice.

The Registrar should take all possible measure to ensure that the nominated adjudicator is competent enough to reach just outcome within the stated time limits. The prospective adjudicator must adhere to a specific code of conduct developed by the Registrar replicating its counterpart of Singapore Mediation Centre (SMC) such as raising any actual or apprehended conflict of interest before accepting nomination and undertaking to adhere to the time limits¹³. To have some flexibility, the adjudicator may formally request additional specific time from the party referring the claim to the Registrar in order to accept nomination. The adjudicator must notify the Registrar and both parties of his acceptance or decline within four days of receiving the referral notice. During proceedings, the adjudicator must dismiss the application if satisfied that it is not possible to fairly reach a decision within the available time limits because of the complexity of the case.¹⁴

On the other hand, adjudication training should include a compulsory legal training for adjudicators who do not possess appropriate legal qualifications, while lawyers with no proven construction experience should have another compulsory training in construction technology, programming and quantity surveying. Yung *et al.* (2015) addressed the necessity of legal training in Western Australia due to the fact that many submissions for complex claims are prepared by lawyers. To be eligible to adjudicate complex claims, minimum years of experience should be expressly stated but not less than 10 years in dispute resolution and local construction experience. Also, a system for compulsory Continuous Professional Development (CPD) for active adjudicators should be established as recommended by the Wallace (2014:236). Evans (2014) also requested submissions on the necessity of the CPD requirements as part of the review of the WA Act. It is argued that imposing CPD will ensure that adjudicators are well informed and up to date with the relevant development in case law.

Unsatisfactory adjudicator's performance should be closely monitored and formally recorded. A complaints system similar to that of SMC¹⁵ should be established and serious investigation should be carried out by the Registrar which may result in imposing a disciplinary action on non-performing adjudicators including formal warning or suspension of registration. Any voided adjudicator's decision under any Australian Act should be seriously scrutinized. Where the reasons for voiding the decision include lack of good faith or substantial errors, the registration of the concerned adjudicator should be temporarily suspended till he undertakes an ad-hoc compulsory training with examination. Should the same adjudicator got another decision voided within five years of the first voided decision, the Registrar may cease

¹² Ibid no. 7

¹³ See (clauses 1,2 and 10), Adjudicator Code of Conduct, Adjudication under the Building and Construction industry Security of Payment Act (Cap 30B) (Rev Ed 2006), Singapore Mediation Centre

¹⁴ See *Balfour Beatty Construction Ltd v Lambeth London Borough Council* [2002] EWHC 597 at [36]

¹⁵ See (clause 9) of Adjudicators Code of Conduct, Singapore Mediation Centre

renewal of registration or cancel it.¹⁶ The Qld model uniquely states that the adjudicator would NOT be entitled to recover his adjudication fees if his decision was overturned by a competent court on grounds of lack of good faith¹⁷. However, it will be advantageous to include quashed decisions for other substantial errors to limit the influence of legislator's support and give adjudicators more incentives to turn their minds intellectually into the cases before them. However, it may be too irrational to waive the whole fees, so proportionate fee deduction may be decided by the Registrar in favour of the aggrieved party.

Adjudicator's Powers

Complex claims commonly involve various sophisticated technical or legal issues, whereas most of eligible adjudicators can't practically possess such collective expertise to turn their minds reasonably into all presented arguments. Therefore, in any complex claim, the adjudicator should be equipped with inquisitorial powers similar to adjudicator's powers under the UK model such as taking the initiative to ascertain facts and law, engaging experts and receiving and considering oral evidence in conferences.¹⁸ To clarify and refine the proposed powers further, the adjudicator should be allowed to use his own knowledge and experience but should request further submissions from the parties on such opinion or any other issue to ensure fairness. However, he should be empowered to give deadlines and limit the length of submissions. He should allow legal representation in conferences but should be limited as the adjudicator finds appropriate for efficient conduct of proceedings and avoiding unnecessary expenses¹⁹. To avoid the shortcoming of dealing with expert reports as mentioned by Skaik *et al* (2015) or where the differences between experts are enormous, the adjudicator should call for a conference with experts and conduct hot tubing, in which both experts are examined concurrently and allowed to cross examine each other. Atkinson and Wright (2014) argued there is no reason why such arrangement is not implemented in adjudication where the adjudicator can receive live expert evidence. If the adjudicator found it necessary to request further submissions, engage experts, arrange testing or conduct conference, he may request an additional time (up to 5 business days) from the referring disputant only to avoid potential tactics of some respondents who may not have the same claimant's incentive to reach reliable and robust outcome. Sheridan and Gold (2014) noted that when that party does not approve such additional time, the adjudicator should resign if it is unfeasible for him to reach sound outcome and he should warn the applicant about this possibility when requesting the additional time. These provisions will not only improve the procedural fairness but also help adjudicators understand complex legal or technical matters, so the soundness and reliability of the adjudication outcome will be definitely improved.

Review of adjudication decisions

Marquet (2015) noted that although the Full Court supports Supreme Courts in remitting invalid adjudications, even if the legislation is silent about it, to the original adjudicator, it is not preferable option being lengthy, complicated and against the intent of the legislation. According to ALRS (2014: 67), it is preferable to keep any merits review process away from expensive prerogative writ proceedings that undermine adjudication by raising jurisdictional issues leaving the actual disputes

¹⁶ This approach adapted from 'Code of Conduct for Authorised Nominating Authorities', Building and Construction Industry Security of Payment Act 2009, South Australia.

¹⁷ S 35(6) Qld Act.

¹⁸ See (s13, part 1), Scheme for Construction Contracts Regulations, UK.

¹⁹ See S 67, Construction Contracts Act 2002, New Zealand

unresolved. The availability of informal review in the WA²⁰ and Victoria²¹ do not address these concerns as the review is limited to few jurisdictional issues rather than the merits of the dispute. To control the overall cost and improve the finality and informality of statutory adjudication, judicial review should be reduced as practical as possible by establishing a fast track internal review system of the merits of adjudication decisions. The Singapore model is the only statutory adjudication regime which provides such excellent mechanism for aggrieved respondents²². According to Christie (2010), such mechanism is worth serious consideration by Australian Parliaments envisaging reform of their existing schemes. According to the SG Act, the respondent must pay the adjudicated amount to the claimant in the first place to be entitled to apply for review.²³ The respondent may apply to the ANA for the review within 7 days²⁴ of obtaining the adjudication decision if the adjudicated amount exceeds the relevant response by \$100,000 or more. The ANA should appoint one adjudicator or a panel of three adjudicators if the difference exceeds \$1 Million.²⁵ The adjudicator(s) must issue the decision within 14 days²⁶.

To refine and harmonize the inclusion of this system within the roadmap, the review should be further limited to complex claims as defined earlier. The respondent should not appeal the original adjudication decision in court unless having the case reviewed by this mechanism in the first place.²⁷ Also, the review adjudicator should be selected from the next higher category in the grading scale. The panel of adjudicators should be only needed if the original decision was issued by a senior adjudicator with the highest grade. The review adjudicator(s) must issue the decision within an equivalent timeframe to that of the original adjudicator under the legislation. The identity of the original adjudicator should not be disclosed to the review adjudicator(s). It is worth noting that the proposed review system may not be urgently required if all the previous pit stops of the roadmap are adopted in the legislation. The review system acts as a safety net that will not only improve the accessibility, certainty and precision but also increase the confidence in the final outcome avoiding lengthy and expensive legal proceedings in arbitration or court on the same payment dispute.

CONCLUSION AND FURTHER RESEARCH

Recently, statutory adjudication in Australia has received increasing criticism regarding its unsuitability to deal with technically and legally complex payment claims, where adjudicators are under pressure to consider substantial volumes of submissions in very tight timeframes. Criticisms have been directed at, inter alia, adjudicator's appointment and regulations, procedural fairness, jurisdictional powers and lack of finality. This paper reviewed the features of successful binding dispute resolution in the context of complex claims which include procedural fairness, accessibility (speed and affordability), finality and informality. Then, it briefly reviewed the evolution of Australian SOP regimes. Finally, the paper proposed the Qld model as a benchmark for the envisaged roadmap to effectively deal with complex payment disputes with proposed measures of further improvement.

²⁰ S 46, WA Act.

²¹ S 28 (b) of Vic Act.

²² S 18, Building and Construction Industry Security of Payment Act 2004-Singapore "SG Act"

²³ S 18 (3) SG Act

²⁴ S 18(2) SG Act

²⁵ See S 10(1) the Building and Construction Industry Security of Payment Regulations 2005.

²⁶ S 19(3) SG Act

²⁷ See RN and Associates Pte v TPX Builders Pte Ltd [2012] SGHC 225 at [61] where the appeal on grounds require the re-opening of the merits of the case was rejected since the review system was not invoked first.

The paper asserts the need for further investigation to ensure the Qld model will lead to a better overall outcome. The Authors propose specific pit stops for the roadmap to improve the Qld model drawing upon the collective strengths in other legislations and commentaries. The measures include establishing criteria of timeframes of complex disputes, improving the appointment and regulation of adjudicators, equipping adjudicators with inquisitorial powers and creating a system to review the merits of adjudication decisions adapted from Singapore model. The paper findings are presented as blunt instruments or hypotheses to inform the subsequent empirical research which the authors are currently undertaking to further investigate, strengthen and validate the proposed pit stops in order to optimise the statutory adjudication of complex payment disputes in Australia.

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RISK MANAGEMENT

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WHAT IS RISK? CONSTRUCTION ACTIVITY NEAR HAZARDOUS INFRASTRUCTURE

Jan Hayes¹, Vanessa McDermott and Helen Lingard

RMIT University, Centre for Construction Work Health and Safety Research, Melbourne, Australia

Construction management has a strong safety focus directed primarily at reducing risk to workers. There is a special class of construction work that has the potential for a different set of safety issues – work that could damage hazardous infrastructure with possibly catastrophic effects for workers and the public alike. The natural gas pipeline failure as a result of car park construction in a light industrial area at Ghislenghien, Belgium in 2004, which resulted in 24 deaths, is one such example. The primary focus of this research is a case study regarding project-related construction activity around high pressure natural gas pipelines in Australia. Drawing on data gathered from in-depth interviews, alternate definitions and meanings of risk are explored amongst stakeholders who are responsible in some way for work near or around high-pressure gas pipelines. The research uncovered perceptions of risk from project personnel in various parts of the supply chain, couched in terms of project delays, legal and insurance obligations, as well as reputation management. The research demonstrates that, whilst damage to buried assets is recognised as something to be avoided, awareness of the potential for major disaster is poor. Further, supply chain contractual structures based on 'pay per meter' and risk control strategies relying solely on enforcement and procedural compliance, create a safety environment that is ineffective and dangerous. Responsibility for risk is shifted down the supply chain and yet field personnel are exposed to incentives for timely project completion. Consequently, strikes or near misses may result as sub-contractors seek to avoid perceived 'unnecessary' time delays and any associated financial impact. The research shows that efforts to reduce the potential for pipeline strike need to be targeted at organisational and supply chain structural changes, rather than simply aimed at worker risk perception and enforcement of safety compliance strategies targeted at field personnel.

Keywords: risk, health and safety, contracting, motivation.

INTRODUCTION

Construction management has a strong safety focus, but this is directed primarily to reducing risk to workers from the physical hazards of their specific tasks. When work is undertaken close to hazardous infrastructure, the potential for catastrophe exists. This was dramatically illustrated in Ghislenghien, Belgium in 2004 when construction of a car park damaged a high pressure natural gas pipeline. When normal pipeline operations resumed some time later, the pipeline ruptured resulting in 24 deaths, mainly amongst emergency services crews (Mahgerefteh and Atti 2006).

In Australia, analysis of pipeline damage events has shown that 86% are caused by people outside the pipeline sector working near buried infrastructure (Tuft and Bonar 2009). Such events are effectively 'near misses' for Ghislenghien type events. For the

¹ jan.hayes2@rmit.edu.au

gas pipeline sector, this provides a significant incentive to better understand the motivations of those who are responsible for such work.

This paper reports on some of the initial findings of research commissioned by the pipeline sector into attitudes towards risk of those involved in work near pipelines. It addresses a single case study of a large infrastructure project that involves significant construction activity near pipelines. The aim is to reveal specifically how relevant stakeholders comprehend risk and responsibility for prevention of pipeline damage or failure.

The case study project uses typical supply chain arrangements with project management retained in-house but responsibility for detailed design, installation work planning and activity managed by a complex chain of contractors and sub-contractors. All construction work is done on a pay per meter basis.

The analysis is based on an organisational view of accident causation and prevention as illustrated by James Reason's Swiss cheese model (1997) and the work of the high reliability researchers such as Weick and Sutcliffe (2001). In this way of thinking about safety, the performance of all components in the system is interlinked and the primary responsibility for safety rests with management, rather than workers in the field. We also draw on literature regarding error management (Reason 1990), proceduralisation (Bourrier and Bieder 2013) and the role of rules (Hale and Borys 2013a, b).

METHOD

This research uses a case study approach in order to develop a detailed and nuanced understanding of the perceptions of individuals through the supply chain of one construction project. As such, it makes no particular claim to generalizability instead relying on the value of case studies as concrete, context-specific knowledge that is critical for expert learning (Flyvbjerg 2006).

The research primarily draws on interviews with representatives from a case study organisation (CSO) involved in construction of a large-scale infrastructure project and their contractors (15 interviewees). Interviews with pipeline industry personnel (20 interviewees) also inform the results. These exploratory conversations aimed to ascertain the differing conceptualisations of risk including how such perceptions are framed and why. Further data is drawn from a content analysis of policy and procedural documents. Interviews were transcribed for analysis. Direct quotes were extracted regarding motivation, primary task and governance frameworks. These were then analysed in more detail to establish similarities and differences in attitudes to risk, safety, worker behaviour and organisation of work.

RESULTS AND DISCUSSION

In all cases, these descriptions are taken from the words of interviewees. Our focus is therefore on work as done (or at least as perceived to be done), rather than work as described in formally documented systems. We also emphasise the social aspects of work – who interviewees believe to be responsible, how they report on actions of others, what they believe to be important etc.

Attitudes to Risk

The first key issue revealed by the data is interviewees' understanding of the primary task of the CSO - rolling out a national infrastructure project on time and within budget. They do not (with a few minor exceptions) conduct fieldwork themselves, but

rather operate a complex chain of what they call Delivery Partners who manage contractors and sub-contractors across the country on their behalf. Nevertheless, the CSO project could potentially interrupt supply or damage a high pressure gas pipeline and attitudes to the risk that this poses are therefore relevant. Across all interview participants, the risks associated with strikes to underground services generally were conceptualised and described in terms of the possible consequences using words such as ‘potentially huge’, ‘catastrophic’ and ‘devastating’. But what are these consequences of concern?

In addition to safety, other identified risks included negative media coverage, and thus negative public perceptions of the reputation of any organisations that may be implicated in the event of a major strike or any interruption of supply eg:

“... it's our brand, it's our name, it's our reputation that is on the line because no one ever, if you ask anyone's that's going down the street, it's not ... the Delivery Partner ... So it is about us, it is our name and people will see our name and associate us with that damage before they associate the actual person who done the damage ... it's definitely a brand issue.” CSO 06

Other risks identified by the CSO representatives and contractors included damage to the pipeline asset and other infrastructure, subsequent remediation costs as well as economic consequences from interruption of supply due to a third party strike.

“Safety there's obviously a high risk or potential high consequence kind of impact. It'd be financial risk as well. I guess they're the two main ones aren't they? It's an environmental risk as well and it would be a risk to our reputation and our good name. It'd obviously be well publicised if something did happen.” Civil Contractor 03

“So, it's a significant problem ... the infrastructure that would be damaged, buildings, housing, road infrastructure, electrical infrastructure, water infrastructure, stormwater infrastructure, I mean, it's all, it's just a knock-on effect.” CSO 01

Other interviewees were more concerned about delays following an incident and the legal liability that could follow. As these CSO participants and a civil contractor engaged by a CSO Delivery Partner indicated:

“... there's delays in the build, there's ... It's the actual reporting time, interviews, and all that sort of stuff” CSO 10 and 11

“Yeah, I guess ... the first factor would be our legal liability as a [body with statutory responsibility] to engage with our contractors and Delivery Partners.” CSO 03

“Basically, our job with drilling is to get a new service from point A to point B. Obviously there is a lot of infrastructure in the ground already. 1) We don't want to damage it to cause down time; 2) the biggest thing is safety. We don't want the guys to get hurt.” Civil Contractor 02

Importantly, whilst stressing that the types of risk were not articulated ‘in any particular order’ and despite senior management claims that ‘safety is the first value in the company,’ worker safety or broader concerns around community safety were often some of the last aspects to be cited.

Perhaps the clearest indication that pipeline strike is not primarily a safety issue for the CSO is the fact that risk from all buried assets is treated equally. As one interviewee explained:

“... I don't think we really distinguish between them [types of buried assets], suffice to say that there's a work practice process going on that our contractors and workers need to manage.” CSO 03

Of course whilst the business risk is similar, the safety implications of striking a high-pressure gas line are completely different to that associated with damaging telecommunications cabling. For the pipeline industry, avoidance of pipeline strike is desirable because security of supply is their primary business goal and the public service linked to that is the highest priority. For the CSO, pipelines strikes have a different relationship to business objectives. On schedule and budget performance of their project is paramount and any asset strike, including pipelines, poses a risk to that.

Beliefs About Why Strikes Occur

Many CSO interviewees spoke about incidents of damage to buried assets in general terms and offered their opinions as to why they occur despite their efforts to eliminate this problem.

Generally speaking, there are two alternative ways in which errors by field personnel can be described (Hayes and Hopkins 2014: Chapter 4). The first is an explanatory paradigm that seeks to understand why an individual behaved in a particular way and so how this might be avoided in the future. These explanations are found in the organisational view of accidents described earlier.

Explanations of the behaviour of field personnel can also be made using an 'error management' approach to safety (Rasmussen 1982, Reason 1990) which focuses on the cognitive classification of errors as slips, lapses, mistakes or violations. Such classifications can also provide insights into the individual and organisational causes of error. Unfortunately the focus sometimes moves to a normative paradigm which attributes accidents to individual fault (Dekker 2007). In this paradigm, error would be eliminated if only workers behaved properly.

CSO people interviewed to date are largely office-based personnel, although some of them have roles involving site audit. A clear common theme in their explanations of why accidents occur is that field personnel are at fault. Their explanations are normative in several ways and so are focused on faults with the workers themselves, rather than providing any explanation as to why workers might have behaved in particular ways.

The first commonly proposed reason for errors in the field is lack of knowledge. Workers in the field make errors because they just don't know how to do the work in the right way. For example:

“I think people mostly are unaware of the hazards, they just don't know.” CSO 09

“So people see a marker and they go, “Oh well gas line must be under here so I'll be right.” Okay, so the different methodology being used by the different utilities is important for these guys to understand.” CSO 04

This is often an insidious way of shifting blame onto frontline personnel. Lack of knowledge can perhaps be an indication that improved communication and training is needed, but it is often framed instead as meaning that workers are ignorant or even stupid. Some of our interviewees were of this view. As another CSO person told us:

“It's about workflow management and laziness. Some of our Delivery Partners, their field people are overworked or just downright lazy ... You can't fix stupidity.” CSO 13

This individual is putting forward two normative explanations for worker errors - stupidity and laziness. Another normative explanation given by several interviewees was complacency or carelessness.

“Not enough due care and attention ... is there the danger that as people do tasks more frequently ... there’s a degree of complacency, 'It hasn’t happened to me, it’s not going to happen to me,' that sort of thing.” CSO 02

“You should not put a shovel in the ground before you do a [one call system]. The information’s there, it’s more interpretation I suppose, comes down to due diligence, due care.” CSO 06

In summary, the CSO reportedly has a chain of contractors who employ workers who are stupid (don’t know what they should do, despite having been told/trained), lazy (know what they should do but do something requiring less effort), careless (know what they should do but don’t pay sufficient attention) and complacent (know what they should do but ignore dangers). These explanations put aside consideration as to why people may have behaved in a particular way and as such are inconsistent with an organisational view of accidents as described in the introduction. Without that broader perspective, any efforts aimed at improving performance must focus only on enforcement of rules and punishment for deviation from the required behaviour.

Risk Shifting

There is an alternative explanation as to why workers do not always follow rules. In the case of the CSO, a minority of interviewees thought that there may be organisational reasons why workers behave ‘badly’, specifically, some workers may engage in these acts based on their belief that they are doing the right thing and in order to meet project deadlines or ‘get the job done.’ This type of routine violation is well known in the safety literature (see for example Iszatt-White 2007) and there is evidence of these types of pressures in the data:

“... I've seen our contracting team do the wrong thing in not getting their [one call system documentation] or getting a permit in place. It's about timelines, trying to get the work done, pressure from further up in completing that job on time and under budget. That's the whole thing, because the longer you have those crews out there or anything like that and they work into overtime, it may not have been budgeted for. So all those sorts of commercial issues come in for a contractor” IND-07

“Everything has a deadline, so at the end of the day, safety plus quality plus productivity should equal the end result. Sometimes we forget, we just look for the end result or for the target and the pressure to build can affect that. ... we've got, inside the company and outside the company, people driving ... the quicker you get a job done the more margin you make.” CSO 07

These comments highlight an important point that emerges from the data. CSO interviewees have indicated that the main reason for avoiding pipeline strikes is because of their time and cost impact on the project. However the reasons for avoiding the measures put in place to prevent strikes is also the time and hence cost involved. Rather than a question of safety, we now have simply two financial motivations that are fungible.

CSO interviewees were reluctant to see this link. One senior CSO manager stated that *“... getting paid by the metre might be a factor, but it’s not the root cause. I just think that there are a number of root causes and incentives or payment is only part of it”*

[CSO 01]. When probed, this participant went on to criticise the field contractors because they are “*poor at identifying where the assets are and exposing the assets*”. In other words their failure to follow process is the ‘root cause’ of accidental asset strikes. This illustrates the tendency for CSO personnel to ‘shift’ responsibility – and blame – for any accidental incursions away from any organisational or structural factors to the level of the individual contractor or frontline worker.

In summary, the CSO attempts to address third party activities around pipelines through specific systems and processes to govern work activities. Third party activities are subject to surveillance and monitoring using an ongoing audit process to ensure compliance with particular systems and processes as well as legislative frameworks. Underpinning these systems and processes are strongly held views that equate compliance with prevention of pipeline or asset strikes. As one CSO representative explained: “... *we just oversee it based on these guys following their own processes. And they have great ones and it's proven, like probably 98% of the time, had they adhered to that, their own process, it wouldn't have happened*” (CSO-10). This person seems to be allocating 98% of the responsibility for pipeline strikes to the workers and only 2% to problems with processes. In other words, a risk governance framework in the form of systems and processes is equated with safety.

Governance systems and processes

To manage the risk of pipeline strikes, the CSO implements particular systems and processes. Risk management, and thus public and worker safety, is conceptualised as compliance with specific governance frameworks that are articulated in legislation. The following comment emphasises that in the view of CSO interviewees, responsibility, and accountability, ultimately rests with the Delivery Partner (principal contractor) to follow and ensure compliance with rules that are fixed because they have their origin in regulation and liability:

“Yeah, well that sub-contractor would be responsible for it because it's their responsibility to get the [one call system] plans and locate the assets so they have to follow the rules. The principal contractor would wear obviously some of that responsibility if there were a death or anything like that and obviously up the chain. So that's why everyone has to have their due diligence up to the client, but the main person would be that sub-contractor.” CSO 12

Whilst clear identification of roles and responsibilities is important, as we can see, the data again reveals a tendency amongst CSO participants to allocate responsibility, and thus liability for errors to Delivery Partners or other frontline personnel. There is no sense that the primary goal of CSO interviewees is to protect the public from disaster.

This exclusively top down and highly rigid approach is reflected in the way that the CSO behaves. The CSO devolves responsibility for safe work systems and processes to their Delivery Partners, or principal contractors. However, these groups as well as any sub-contractors they may engage are required to align their policies with the CSO's overarching risk-based compliance framework, including appropriate training and supervision. Compliance with those processes is audited by the CSO. For example:

“My job is to manage a team of people whose tasks involve primarily audit and inspection for compliance to legal and other regulations of our Delivery Partners” CSO 03

A significant aspect of the CSO's array of systems and processes are 'critical risk controls (CRCs),' stipulated by top management that specify mandatory systems for working near underground assets. Of course top management attention to critical safety issues is to be encouraged as a lack of understanding of the impact of top management decisions on safety has been shown to be a major factor in several serious accidents (Hayes and Hopkins 2014). Having said that, Schein (2013) has described the need for what he calls 'humble inquiry' on the part of top management in order to understand the state of safety, promoting an attitude of listening, rather than telling. Telling is the dominant communication strategy from the CSO to its Delivery Partners who are contractually obligated to adopt and orient their own systems and processes around these CRCs. As these comments from CSO representatives and a Delivery Partner employee stated:

"They are contractually obligated to the critical risk controls. So they're given a copy at tender." CSO 01

"... we told [the Delivery Partners] that they had to align to [CSO critical risk controls] and get the systems to align to it. Then we did some audits on that to make sure that that included all the relevant things that we thought if you implement you reduce your risk of damaging the assets." CSO 12

At the CSO, safety is equated with, but ultimately secondary to, risk mitigation, which is attained through rule-based compliance that is monitored and audited using systems and processes including critical risk controls.

Compliance and proceduralisation of risk

Adherence to an overly compliance-based approach to safety, or the proceduralisation of risk, is problematic for safety. This is not to suggest that rules and procedures are not important. They play a key role in managing risk and are essential elements for any modern organisation to function effectively but a problem arises when procedures are seen as a universal panacea. Bourrier and Bieder (2013:3) provide a succinct description:

Historically, to put it bluntly, proceduralisation has been the response to flaws identified through accident investigation and analysis. It was also the only response that made sense in a world where beliefs on safety were (and still are in many places) based on a model which assumes that safety results from reliable equipment, good procedures and processes, well-behaved operators and well-designed organisations.

As we have seen earlier, the CSO takes the view that 'safety' is achieved by exactly these types of measures – good procedures and processes and well-behaved operators that adhere to procedures or rules. The world is, in fact, far more complex than this.

Rules, or procedures, can either act as an aid, supporting workers in a difficult task or as a standard to which compliance can be enforced (Fucks and Dien 2013, Hale and Borys 2013a, 2013b). There is evidence of this second approach in the CSO data. For example, CSO rules about prevention of pipeline strikes are described as 'rules that cannot be bent' and as 'hard and fast rules of what people must do' [CSO 01]. Nevertheless, evidence that this approach is not successful is also illustrated by that same participant who goes on to note, 'but we're still hitting things' [CSO 01].

A further issue with the proceduralisation of risk is that proceduralisation itself becomes a proxy for safety issues i.e. compliance with the process becomes the goal in its own right. Adherence to process, accompanied by a concern to manage liability,

drives a push towards a reliance on audits (Power 2007). This is evident across the CSO interviews:

“So firstly, we see that ... they’ve done a risk assessment and identified all the different activities and training required ... we look at the systems first, ... then we monitor them, that they’re compliant to their own systems ... “ CSO 04

“ ... we would audit that they have followed the processes ... they have their own processes that they have to follow ... we would turn up and do an interaction on a particular crew on a particular day, might be one week, might be one a day.” CSO 06

From this perspective, failure to comply or deviations from procedure become easier to understand. However, this also means that the social processes attached to the daily uncertainties and complexities, or the *“real conditions under which safety is produced”* are neglected (Bourrier and Bieder 2013: 3). The literature shows us that in reality, safety results from the complementary interaction of formal prescriptions as well as informal rules (Fucks and Dien 2013). A reliance on procedures can create a context in which individuals forget, neglect or avoid anything that is not formalised. Increasing formalisation of procedures, or bureaucratisation, was identified in early organisational sociology literature, which point out that bureaucracy can lead to over-compliance. In that type of situation compliance with rules becomes the aim rather than a means to a goal (Merton 1968). Such over-bureaucratisation in an organisation can result in the *“transformation of people into robots”* (Fucks and Dien 2013:32). This can also contribute to a decline in actions that perform and enhance safety, such as the ability to consider a variety of elements, an analytical and critical sense at work that includes taking the initiative and questioning procedures or practices that are seen as problematic, ineffective or too complex.

This is an important point because workers' willingness to reflect on, and then if necessary adapt, their work practices is challenged by procedures that contribute to perceptions that actions taken outside the rules are ‘too risky,’ particularly if people are convinced that those actions will lead to negative employee evaluations (Reason 1997). Added to that loss of autonomy and reflexivity, and despite being underpinned by an intention to enhance safety and worker responsibility, reliance on procedures and rules can contribute to a ‘blame culture’ where analysis of any organisational failures means that individuals are stigmatised as responsible for those failures (Dekker 2007). This type of human error paradigm is often used to reduce ‘failure’ to the individual level but neglects to consider broader organisational or social factors that might contribute to why individuals make ‘wrong’ decisions. As we have already seen, there is evidence in the CSO data that errors by field personnel are perceived as the ‘root cause’ of why accidents occur.

Safety research indicates the many ways in which a strict compliance approach such as that adopted by the CSO is unlikely to result in the best safety outcomes. This then raises the question as to why the organisation has chosen to use this method of managing what they see as a critical risk. It seems that, rather than directly addressing the difficult problem of managing the potential for a catastrophic pipeline rupture whilst meeting ambitious project schedules, the CSO pass on responsibility for the issue and, critically, for management of uncertainty, to their sub-contractors as the following extract of interview illustrates.

“... we expect our contractors to be diligent. But with the rates that are paid, via [CSO] or not so much [CSO], but ... the Delivery Partner, the rates that they pass onto their contractors, they take a lot of the margin out. So the Delivery Partners, it’s

metres in the ground to them, and while they're stopped and potholing and all of that, they're not getting paid for that. So it's a commercial impact." CSO 13

This comment indicates that as far as this interviewee understands it at least, contractors are required to follow procedures and yet the risk of variation in work that they are required to do as a result of those procedures is not paid for by the CSO or the Delivery Partners.

In summary, the CSO attempts to control safety outcomes by using a top down overly proceduralised governance structure. Indications are that it is not highly successful as reportedly strikes to underground assets continue to occur (although we have no specific statistical data on this). In considering why such an approach to safety has been taken, we have noted that the business model of the CSO appears to provide strong justification for adopting the strict compliance model that the CSO has put in place because it shifts financial risk away from the CSO itself.

IMPLICATIONS FOR THE CONSTRUCTION INDUSTRY

Our research to date indicates that within the CSO, there is a high awareness of the risk of damage to underground assets but this is seen primarily as a business risk to the organisation itself rather than a significant safety issue. The potentially catastrophic safety consequences of a high pressure gas transmission pipeline rupture are not widely understood. The San Bruno disaster in 2010 which caused eight public deaths and burned down this suburb of San Francisco illustrates the destructive power of a major leak from a high pressure pipeline (Hayes and Hopkins 2014). Construction activity could result in a pipeline accident on a scale not appreciated by the CSO and, we suspect, by many other construction organisations outside the pipeline sector.

In this case, the way in which project work is structured shifts management of low frequency but high consequence accidents to the bottom of the supply chain. We make no claim to generalise the findings and yet we note that this contractual structure is far from unique to this project. Privatised utility operators are constrained in their ability to address this directly (even if they are aware of the problem) as they have limited powers to mandate actions by other commercial organisations. There is clearly a role for government here but effective safety risk management also requires structural changes in order to align financial and business incentives with the desired safe behaviours throughout the supply chain.

This research is continuing with further interviews aimed to address two main groups - workers in the field and other organisations such as local councils that commission construction near hazardous linear infrastructure.

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MODELLING ECONOMIC RISKS IN MEGAPROJECT CONSTRUCTION: A SYSTEMIC APPROACH

Prince Boateng¹, Dominic Ahiaga-Dagbui², Zhen Chen³ and Stephen Ogunlana⁴

^{1 and 2}Scott Sutherland School of Architecture and Built Environment, Robert Gordon University, Aberdeen, AB10 7QB, Scotland, UK

^{3 and 4}School of Energy, Geoscience, Infrastructure and Society, Heriot-Watt University, Edinburgh, Scotland, EH14 4AS, UK

Megaprojects present significant economic risks to their financiers and sponsors. Factors such as inflation, cash flow issues, material and energy price hikes and change in government policies can cause such capital intensive projects to overrun planned budget and schedule allocations. Where the project is a commercial asset, delayed completion time and cost overruns usually have significant impact on the profitability of the project as well as the estimated returns on investment over the operational phase of the project. Understanding the dynamics of specific risks can thus be very crucial in designing containment measures to deal with their likely impact on the project. Using a case-study of the Edinburgh Trams project in Scotland, the dynamics of identified economic risks in transportation megaprojects is presented. Through the combination of interviews, questionnaires and non-participant observation, different economic risk factors were first identified. The identified factors were then prioritised using Analytical Network Process (ANP) to establish the most salient economic variables on the Tram project. Some of these factors include material and energy price increases as a result of the 2008 recession, as well as inflation and changes in government funding policies. The selected factors from the ANP were then modelled within a System Dynamics (SD) framework to appraise their measured economic impact on the project to gain a fuller understanding of the interrelationships between the variables in the system. The mean impact of economic risks on Edinburgh Trams was estimated to be about 22%.

Keywords: analytical network process, cost overrun, economic risk, Edinburgh Trams, megaproject, system dynamics.

INTRODUCTION

An estimated USD 57 trillion investment will be needed to finance infrastructure development around the world by 2030, according to a report by Dobbs *et al* (2013). This represents an ambitious increase in infrastructure spending when compared to historical trends. Unfortunately, a significant number of capital intensive projects experience considerable multi-year and multi-million schedule and cost overruns (see, Ahiaga-Dagbui and Smith 2013, Ahiaga-Dagbui and Smith 2014a). One of the most cited sources of cost and schedule overruns in the literature is the ineffective management of risk and uncertainty (Creedy 2006, Okmen and Öztas 2010) largely due to a poor understanding of the systemic and dynamic nature of projects (Eden *et al.* 2005). Arguably, the nature of construction projects make them particularly prone to the effects of risk and uncertainty – each project is unique, often complex and

¹ p.boateng@rgu.ac.uk

dynamic; projects are exposed to the vagaries of the weather (not in a controlled environment); ground conditions are largely unpredictable; large public projects for example usually take several years from conception to eventual project completion, making predictability rather challenging. However, even though risk and uncertainty seems to pervade the construction industry, all too often, they are either ignored or dealt with in a completely arbitrary manner using rules-of-thumb or contingency funds (Ahiaga-Dagbui and Smith 2014b). Project risk matrixes or registers have also been extensively used to identify or quantify risk. However, these do not account for the interactions or dynamics between risk factors. The crucial skill in risk management is not to be able to list or rank different factors as though they were stand-alone, but to be able to see the connections and dynamics between these various factors. As suggested by Ackermann *et al* (2007) different risks occurring at the same time, example, could form a portfolio where the impact of the whole is greater than the sum of the parts. Boateng *et al.* (2013) also found that the inability of project managers to assess risk dynamically in large projects are mostly a major cause of cost and time underperformance of megaproject construction. The aim of this paper, therefore, is to assess the dynamics of key economic risks on large infrastructure projects using a case study of the Edinburgh Tram Network which was completed in 2014. Data from triangulated sources of questionnaires, interviews and non-participant observations was modelled within a framework of Analytical Network Process and System Dynamics.

THE SYSTEM DYNAMICS

System Dynamics (SD) is based on information feedback structure which provides an avenue to understand the structure and dynamics of complex systems. According to Coyle (1996), SD has the capability to model the way information, actions and consequences interact to generate dynamic behaviours, diagnose the cause of faulty behaviours and to tune its feedback loops to get better behaviour. SD is particularly suitable for analysing highly dynamic systems that consist of multiple interdependent components involving several nonlinear relationships. Boateng *et al* (2012) used SD to model the impacts of critical weather conditions on construction activities and to describe its approach in assessing risks in megaproject during construction. Zhang *et al* (2014) developed an improved sustainable development ability (SDA) prototype model using SD to assess construction projects in terms of their sustainable development value over a project's life cycle. Ackermann *et al* (2007) developed a Risk Filter framework for identification and assessment of risks for a multinational project-based organisation using a systemic approach. Love *et al* (2002) have similarly developed an SD model which enables project managers to understand change and rework in construction project management systems. In this paper, the SD is combined with Analytical Network Process (ANP) to allow expert judgments to be synthesised into numerical values given their specific subjectivity inputs and to prioritize economic risks based on their relative impact on the performance of the project. The risk prioritization results derived from the ANP were integrated into the SD stock and flow modelling process at the risk simulation stage to analyse the behaviour patterns of risks and the level impacts of those risks on project performance over time.

CASE STUDY: THE EDINBURGH TRAMS PROJECT

The case study project is the recently completed Edinburgh Trams Project (ETN) in the UK. The construction involved new bridges, retaining walls, viaducts, a tram

depot and control centre, electrical sub-stations to provide power to the overhead lines at 750 volts, track laying and tram stops. The project was procured mainly using a turnkey contract. The Client, City of Edinburgh Council (CEC), used a private limited company known as Transport Initiatives Edinburgh (TIE) to deliver the tram system. TIE is a company wholly owned by CEC who were responsible for project-managing the construction of the tramway from 2008. The role of Tie was to administer, integrate and coordinate the consultants and principal contractor, a consortium of Bilfinger Berger and Siemens (Rowson 2008). By February 2011, contractual disputes and further utility diversion works resulted in significant delays to the project beyond the originally planned programme. In late 2011, TIE was released from managing the ETN Project. Turner and Townsend (T&T), a project management consultant was brought in by CEC to ensure effective oversight and delivery of the project. Work in 2012 continued smoothly on schedule with a new governance structure under the management of T&T. After major scope reduction due to large cost overruns, the project was eventually completed three years late at a reported £776 million as against the initial project cost estimate of £375 million (Railnews 2012, City of Edinburgh Council 2014).

DATA

The data for this research was derived from triangulated sources i.e. interviews, a questionnaire survey and structured-case study of the Edinburgh Trams Project. The data was collected between April 2011 and December 2013. 300 questionnaires were distributed to members of the project's client team, site management team, consultants, subcontractors and suppliers. The project was visited twice a week throughout the data collection period for onsite non-participatory observations. Documentary evidence were also obtained from Audit Scotland, the main contractor, Bilfinger Berger (BBS), as well as other key participants involved in the project. Also, unstructured interviews were conducted and used primarily to determine the economic risk dynamics that influenced the cost, time and quality performances of the project. Coyle (1996) advocated such an approach for identifying and establishing dynamic relationships as the triangulated data sources allow for the generation of a rich database to develop the SD models.

SUMMARY OF QUESTIONNAIRE AND ANALYSIS

Out of 300 instruments delivered, 140 completed questionnaires were successfully retrieved, representing a 46.67% response rate. Among the 140 responses, 99 (71%) play a role as contractors' team member (Project engineer, Project manager and Site engineer), 17 were part of the consultant's team, 16 were from client's team while the remaining 8 did not provide any detail regarding the role they play in the ETN project. Majority (51%) of respondents worked on the project between 3-5 years, 43% for 1-2 years, 3% for less than a year, while 5 respondents (4%) had worked on the project for over 5 years.

To standardize the results gained from each survey participant, the identified economic risk variables were coded and tabulated (See Table 1). Using a Weighted Quantitative Score (WQS) method, Respondent's Mean Scores of Importance (RMSI) were calculated and the results summarised to aid the ANP pairwise calculations. In this regard, the results achieved by WQS are derived by the Equation 1.

$$MV = \frac{1}{n} (\sum_{i=1}^n E_{i(C,T,Q)}) \quad (\text{Equation 1})$$

Where

MV = value of mean scores of importance for each criteria/sub-criteria calculated by WQS.

E = experimental WQS for each sub/criteria expressed as a percentage year of experience multiplied by each participant's score of importance.

C = participant's score of importance for each sub/criteria with respect to cost.

T = participant's score of importance for each sub/criteria with respect to time.

Q = is the participant's score of importance for each sub/criteria with respect to quality.

n = total number of participants in this research.

Based on the rounded mean scores of importance, a pairwise comparison of the economic risk sub-areas was performed with the Super Decisions® software to derive the risk priority values. The pairwise comparison is a process of comparing risk variables in pairs to judge which of each variable has a greater amount of quantitative impact on the project performance. From the ANP computation, project cost, time and quality are each revealed to have equal synthesized priority weights of 0.33 (33%).

Table 1: Extract from Final ANP Decision Making Priority Results for economic risk factors

Risk Priorities											
Economic risks		Mean Values (MV_{Risks}) = $\frac{1}{n}(\sum_{i=1}^n E_{i(C,T,Q)})$			Local Priorities (w)			Synthesized Priorities (W) = $w_{(C,T,Q)} * 0.33$			Risk Priority Index (RPI)
Code	Sub risks	Cost	Time	Quality	Cost (0.33)	Time (0.33)	Quality (0.33)	C	T	Q	
					$w_{(c)}$	$w_{(t)}$	$w_{(q)}$	W_C	W_T	W_Q	$\sum W_{(C,T,Q)ij}$
E_{v1}	Ch. in funding;	8.51	7.18	6.31	0.20	0.14	0.14	0.07	0.05	0.05	0.17
E_{v2}	Taxation;	3.90	2.41	2.42	0.03	0.02	0.03	0.01	0.01	0.01	0.03
E_{v3}	Change in gov.	7.01	6.81	5.84	0.09	0.14	0.14	0.03	0.05	0.05	0.13
E_{v4}	Wage inflation;	3.38	2.34	2.35	0.02	0.02	0.03	0.01	0.01	0.01	0.03
E_{v5}	Inflation change;	2.91	2.08	2.03	0.02	0.02	0.03	0.01	0.01	0.01	0.03
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Values of CI, RI, CR and inconsistency (I) for the pairwise comparison matrix					Criteria	λ_{max}	CI	RI	CR	I	
					Cost (C)	12.49	0.040	1.54	0.03	0.00	
					Time (T)	12.35	0.030	1.54	0.02	0.00	
					Quality (Q)	12.20	0.020	1.54	0.01	0.00	

The local priority values suggest equal importance of the project objectives to respondents during construction of the ETN project. Consistency of respondent's judgment on the level of economic risks impacts on the project as obtained during the pairwise comparison for each risk with the Super Decisions® with a consistency threshold of 0.1 to judge whether the comparison conducted is consistent. Where consistency Ratio (C.R) ≤ 0 , it meant that respondents' judgments satisfy this consistency. If not, the experts had conflicting judgments and therefore, the inconsistent elements in the comparison matrix have to be identified and revised. Analysis of the results in Table 1 indicates that respondent's answers to the prioritization on project objectives during the survey are consistent. Table 1 further presents the maximum Eigenvector (λ_{max}), Consistency Index (CI), Relative Index (RI) and Consistency Ratio (CR) achieved for the economic risk factors in this research. The final Risk Priority Index (RPI) for the economic risk sub-areas is the addition of the synthesized weights of cost (WC) Time (WT) and quality (WQ).

Consequently, the RPI for EV1 is 0.17 (17%). The RPI for each risk variable is the final risk priority index that could be used as an indicator to attract a developer's attention to potential risks that have the highest level of impacts on project objectives. The values could also be imported into the SD to simulate the behaviour of such risks overtime so that appropriate mitigations procedures could be initiated.

DYNAMIC MODELLING OF RISK

The following steps were adopted to in this research to model the dynamics of economic risk during construction phase of the case study:

- i. Problem identification and definition
- ii. Initial model development
- iii. Model verification (using expert opinion)
- iv. Final model development and simulation (analysis of model behaviour)
- v. Model validation using software tools and a case study
- vi. Policy analysis, model use or implementation.

After the ANP's pairwise comparison, a model boundary was formed and a dynamic hypothesis, also known a causal loop diagram (CLD) was developed. The model boundary is used to define the limit within which the economic risk model will operate. It is a representation of "*how far in the future should a modeller consider and/ or how far back in the past lie the roots of the problem?*" Sterman (2010). The CLD contains risk variables that were identified to generate the problem behaviour on the cost and time performance of ETN project. Based on a verified CLD, a stock and flow diagram was finalised in December 2013, by an expert panel comprising 3 project managers, 2 site engineers, 1 system dynamic expert and a risk analyst. A stock is the term for any entity that accumulates or depletes over time whereas a flow is the rate of accumulation of the stock. Figure 1 illustrates the stock and flow model (SFM) which was developed based on a validated CLD. The SMF is developed with material price, economic risks, risk of project time overrun, risk of project cost overrun and quality deficiency in focus. However, the latter is excluded from the analysis in this paper due to lack of data from the real system for validation.

In the SFM, variables such as the economic recession, local inflation rate and material price have direct influence on the controlling system variable material price hike which stocks material price. The stock 'Economic risks' is in turn influenced by several other variables through the economic uncertainties as indicated on Figure 1. It can further be noted that economic risks variable is affected by the economic certainties. Similarly, risks of project time and cost overruns are influenced by escalation in project time and escalation to project cost to stock risks of project time and cost overruns respectively. Further, consideration on the SFM show that a number of variables influence risk of project time and cost overrun through escalation of project time and cost overruns. Due to space limitation, the governing equations used to calculate the system parameters for this model are not provided in this paper.

After the model equation formulation, two assessment tests were conducted to check the structural conditions of the model. First, structure verification was performed to compare the structure of the model directly with structure of the real system that the model represents. To pass the structure-verification test, the model structure must not contradict knowledge about the structure of the real system. As a result, a review of model assumptions was carried out with the help of two Project Managers who are highly knowledgeable about corresponding parts of the real system. Second, a dimensional consistency test was conducted on the SFM. This test was conducted to

satisfy the dimensional consistency of the model. By inclusion of parameters with little or no meaning as independent structural components, often reveals faulty model structure when this test is performed. Messages from Vensim’s built-in function indicated that the dimensional tests conducted on the economic risks model are consistent.

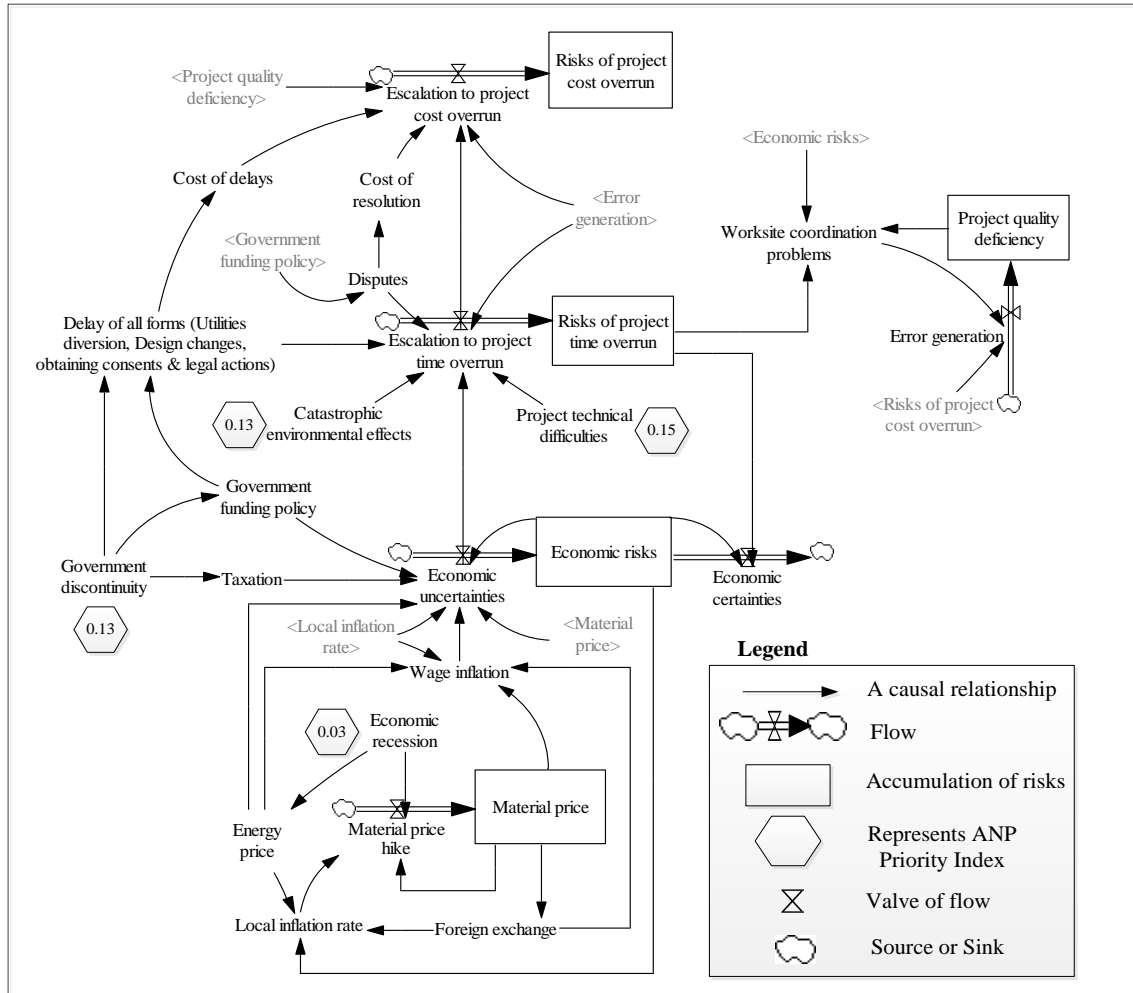


Figure 1: Stock and flow diagram for economic risks

DYNAMIC SIMULATION RESULTS AND DISCUSSION:

In system dynamics simulation, trend analysis is given priority and numbers do not have much significance, however, the numbers should be, as far as possible, close to the real life situations. In the context of the economic risks modelling, the ANP input to the system to conduct simulation is represented in Table 2.

Table 2: Summary of the ANP Inputs

Code	System Variables	*ANP’s RPI (%)
EV3:	Government discontinuity (change)	13
EV8:	Economic recession	03
EV10:	Catastrophic environmental effects;	13
EV11:	Project technical difficulties	15

Also, the outputs indicated on Table 3 revealed the dynamic simulation results under the following time bounds and units of measurements for system variables:

- i. The initial time for the simulation = 2008, Units: Year
- ii. The final time for the simulation = 2015, Units: Year
- iii. The time step for the simulation = 0.125, Units: Year
- iv. Unit of measurement for system variables = Dimensionless

It can be observed on Table 3 and Figure 2 that project time and cost are all impacted by economic risks. The mean impact level of economic risks (PR3) on ETN project is revealed to be 21.50%. Time was the most sensitive to the impact of economic risks. The mean scores of project time and cost overruns of 30.74% and 22.36% respectively on the project.

Table 3: Extract of Summary of the Dynamic Simulation Outputs

		Expected Level of Risk in the project (%)					
		Min	Max	Mean	Median	StDev	Norm
PR3	Economic risks	1.72	33.0	21.5	26.07	10.73	49.86
EV1:	Change in government funding policy	2.21	2.21	2.21	2.21	0.00	0.00
EV2:	Taxation	0.39	0.39	0.39	0.39	0.00	0.00
EV4:	Wage inflation	1.01	1.67	1.50	1.57	0.19	12.41
EV5:	Local inflation	3.29	33.7	22.5	26.67	10.37	46.17
EV6:	Foreign exchange	0.24	1.41	0.80	0.77	0.39	49.42
EV7:	Material price	8.00	47.1	26.6	25.65	13.14	49.42
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
EV23:	Worksite coordination problems	15.9	33.5	25.6	26.90	6.29	24.56

Measured Impact of Economic Risks

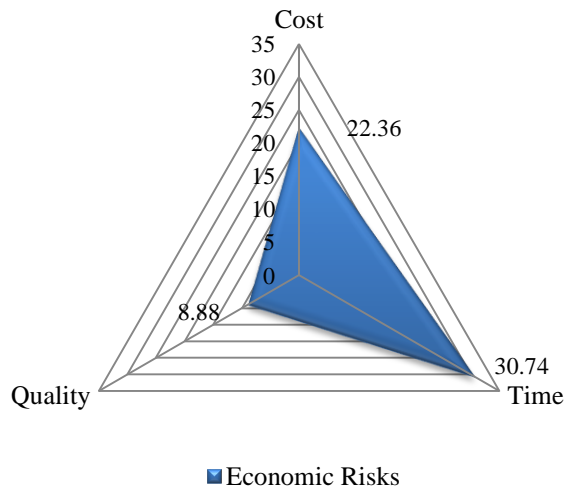


Figure 2: Measured Impact of Economic Risks

Further to the numerical simulation, results from the system dynamic simulation patterns were also generated to investigate the influence of exogenous parameters such as economic recession, government discontinuity, catastrophic environmental effects and project technical difficulties on the project time and cost performances in two ways. First the RPIs used as inputs into the SD were fixed to *no influence* impact level (0%) for the base-runs simulation and secondly to *high influence* impact level (100%) for the current or actual simulation run based on the actual risk priority index

obtained from the ANP pairwise calculations. As seen in Figure 3, the initial dynamic pattern based on the actual simulation run turns to increase steadily even with no risk influence from the exogenous system variables within the first two years of the project before declining after 2010.

However, when the values inputted in the system were replaced with the RPIs, it can be observed that after approximately two years and 48 days (2008-2010.13), the dynamic impact pattern of the economic risks (PR₃) increased steadily to reach a maximum point of 33.03% before declining to a minimum value of 1.72% in year 2015. It is important to note that even with no influence from the exogenous system variables, the level of economic risks impact was as close to 32% in year 2010 and 48 days into year 2011 but declined steadily to 0% in year 2015. From a holistic point of view, whether values of the exogenous variables are changed or not, the overall dynamic patterns for the risks of project time and cost overruns would have increased to a considerable level and would then become a critical point for the megaproject developer to assess what the cause might be. This is where the experience of a project manager's ability to plan for effective risks assessment will come into play. Therefore, SD/ANP based simulation should only substantiate or aid managerial decisions.

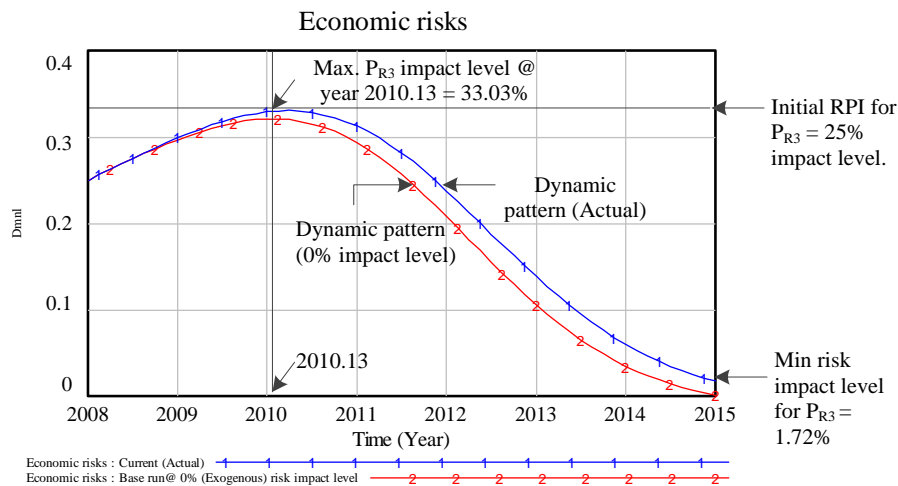


Figure 3: Baserun and actual scenario simulation patterns for economic risks

Up to this point, dynamic simulations have been performed to reveal the level of economic risks impact on the time and cost performance of the case study project. However, the question that still remains is whether one particular project objective experiences greater economic risks impact than those of other objectives? If so, what is the nature of these distinctions and if not, what is the form of the similarities? To provide answers to these questions, a one-way analysis (ANOVA) was used to explore these distinctions using an alpha of 0.001. The impact of the economic risks within the project objectives represents the variability of values for individual project objectives in a sample. In these instances, the economic risk impact within project objectives is a measure of how much an individual objective tends to change over time. The impact of the economic risks between project objectives, by contrast, examines differences between individual objectives and was observed in the multivariate context. By subjecting the results of the level of expected risk impact on the project performance indicated in Table 3 to ANOVA, the results as represented in Table 4 reveal that the F (obtained) is 24.143 and is far exceeding the F-critical value of 7.41 for this test when using an alpha of 0.001. Correspondingly, the observed p-value of 0.000 is well below the chosen alpha of 0.001. By either standard, the result implies that the difference

between the levels of economic risks impact on the objectives of the cases study project is statistically non-significant.

Table 4: One-Way Analysis of Variance: The Extent to which Economic Risks Impact on Project Objectives

Variance	Sum of squares	Degrees of freedom (df).	Mean square	F	P
Between project objectives	13862.771	2	6931.386	24.143	.000
Within project objectives	48232.202	168	287.096		
Total	62094.974	170			

CONCLUSION

This paper presents a combined Analytical Network Process (ANP) and System Dynamic (SD) model that can be used to prioritize and simulate economic risk impact on large infrastructure projects. The impact of economic risks such as increase in foreign exchange and inflation, change in government, disputes, change in tax regime and energy price increases on project schedule and cost were investigated on the Edinburgh Tram Network project. The analysis shows how project time and cost were significantly affected by these economic risks, eventually resulting in a 3-year time slippage and about £400 million cost overrun. Although the behaviour patterns of each impact level of the economic risk towards the project performance is different, it can be concluded that the risks of project time and cost overrun are most sensitive to scenarios in which the dynamic patterns of all risk levels changes at the same time. It was quantitatively shown that schedule slippages seldom occur in isolation. They are usually accompanied by cost escalation on the project. This is because project time is usually intricately linked to the scope of the project, and therefore project cost. Time slippage on the Edinburgh Tram project was largely due to major changes in scope leading to significant disputes and perhaps an overly aggressive timescale for the project.

It is worth mentioning however that the most accurate industry-specific parameter values were not available for all types of risk. However, our scenarios for the dynamic risk patterns covered the most possible parameter ranges obtained on the case study and the results follow the general patterns expected. Nevertheless, the model helps to prioritize identified risks and conduct comparative simulation of different scenarios to investigate the effect of changes in different variables of interest on project performance. As an innovative way of combining ANP and SD to assess risks, the approach will provide a complete framework for understanding the criteria used for evaluating and assigning ratings to system elements and the dynamic interrelationship among those elements. The proposed model could be used by project managers, sponsors and policy makers involved with the procurement of large infrastructure projects to enable a systems thinking approach to project delivery. Later stages of this research will attempt to integrate the impact of other project risk clusters like socio-technical risk as well as environmental and political risk on transportation megaprojects using SD-ANP approach.

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GREEN RETROFIT PROJECTS: RISK ASSESSMENT AND MITIGATION

Xianbo Zhao¹, Bon-Gang Hwang² and Yi Lin See³

¹*School of Engineering and Technology, Central Queensland University, Sydney, NSW 2000, Australia*

²*Department of Building, National University of Singapore, Singapore*

³*EC Harris, Singapore*

The Singapore building industry has been experiencing a trend of going green and the government has set up a target to have at least 80% of buildings being green by 2030. To achieve this target, initiatives have been steered towards retrofitting existing buildings to green buildings. This study aims to assess the risks associated with green retrofit projects in Singapore. To achieve the objective, 20 risks were identified from a literature review. In addition, a questionnaire survey was performed with 30 professionals experienced in green retrofits. In the risk assessment, this study adopted the index of risk criticality (RC), which is the product of likelihood of occurrence (LO) and magnitude of impact (MI). In terms of RC values, “*post-retrofit tenants’ cooperation risk*”, “*regulatory risk*”, “*market risk*”, “*financial risk*”, and “*pre-retrofit tenants’ cooperation risk*” were the top-five risks. Additionally, comparisons were made between traditional and green retrofit buildings. 17 and 19 risks received significantly higher LO and MI values in green retrofits than those in traditional retrofits, respectively, which contributed to the significant differences in RC values of 19 risks between the two groups of retrofits. These results also confirmed the necessity of risk management in green retrofit projects. Furthermore, 28 mitigation measures were collected and received agreement from the respondents. This study contributes to knowledge by providing an understanding of the risks in green retrofit projects in Singapore for both practitioners and researchers. Practitioners can customize their own list of critical risks in green retrofit projects based on the risk identification in this study.

Keywords: green building; retrofit; risk criticality; mitigation; Singapore.

INTRODUCTION

The building and construction industry greatly contributes to the increase in greenhouse gas (GHG) emissions, which leads to global climate change (Wu *et al.* 2014a; Wu *et al.* 2014b). In recent years, there has been an apparent shift towards green construction across the world (McGraw-Hill Construction 2013). Singapore has been viewed as a leader in advocating sustainability in the building and construction industry with its efficient green strategies and initiatives (WorldGBC 2013), and launched the Green Mark Scheme in 2005. Additionally, Singapore’s government has set up a target to have at least 80% of buildings being green by 2030 (BCA 2009; Hwang and Tan 2012). To achieve this target, efforts should not only be directed to constructing new green buildings as existing buildings represent a bigger proportion. Initiatives have been steered towards retrofitting existing buildings to green buildings, and green retrofit had reduced operating costs by 14% over five years, with a payback time of approximately six years for green investment (McGraw-Hill Construction

¹ b.zhao@cqu.edu.au

2013). Construction projects are inevitably plagued with risks (Zhao *et al.* 2014b), and in green retrofit projects, the risks are likely to be beyond those associated with traditional projects. Therefore, to ensure the achievement of the going green target set up by Singapore’s government as well as the success and subsequent benefits of green retrofit projects, risks in the green retrofit projects should be well handled and managed. The objectives of this study are to (1) identify the potential risks in green retrofit projects in Singapore; (2) analyse their risk criticalities; (3) compare the risk criticalities between traditional and green retrofit projects; and (4) provide mitigation measures for the critical risks.

BACKGROUND

In order to reduce GHG emissions, and contribute to the global climate change mitigation efforts, the BCA launched the Green Mark Scheme in 2005. This scheme provides certification for building owners who have met the requirements set by the BCA. Hence, in Singapore, a building is considered as a green building if it has met the requirements of the Green Mark Scheme (Hwang and Ng 2013). In December 2006, the BCA formulated the 1st Green Building Masterplan to encourage, enable and engage industry stakeholders to increase their efforts in environmental sustainability. In 2009, the 2nd Green Building Masterplan were unveiled placed special emphasis on greening existing buildings because existing buildings represent a larger fraction and consume a third of Singapore’s total end-use electricity (BCA 2010). Also, the Green Mark Incentive Scheme for Existing Buildings (GMIS-EB) is initiated to co-fund up to 35% of the retrofitting cost. Furthermore, in 2014, the BCA launched the 3rd Green Building Masterplan. In this Masterplan, a Green Mark Incentive Scheme for Existing Buildings and Premises (GMIS-EBP) is provided to incentivize existing small and medium enterprise (SME) tenants and building owners to adopt energy efficiency, and a Building Retrofit Energy Efficiency Financing (BREEF) Scheme is presented to help building owners overcome upfront costs of energy efficiency retrofits and adopt Green Mark standards for existing buildings (BCA 2014a).

Green retrofit projects are inevitably plagued with risks, including the risks common to all kinds of construction projects and those closely associated with green retrofit. These 20 risks are described in Table 1. In addition to the identification of the 20 risks above, this study also collected 37 risk mitigation measures from the literature review. The detailed description is presented in the section of results and discussions.

Table 1: Risks in green retrofit projects

Code	Risks	Description
R01	Financial risk	A higher certification is usually associated with a greater premium paid (WorldGE 2013). The additional upfront cost associated with green retrofit may threaten the achievement of the schedule and cost objectives of green retrofit projects.
R02	Return on investment (ROI) risk	A company’s budget is usually not structured to track lifecycle cost due to the lack of appropriate financing model to estimate the benefits and costs, making it difficult to record long-term gains from retrofits. Also, the ROI can range widely depending on the building’s age, existing design, purpose, and the level of savings being targeted.
R03	Energy saving uncertainty	There are inconsistent energy savings throughout the building lifespan. One should be conscious that it is an unproven business case to accurately justify the energy saved.
R04	Accreditation of energy service companies (ESCOs)	An ESCO is a company dedicated to the provision of energy efficient technology and services including financing, design, implementation and management of projects. Risk resides where the ESCO selected is not accredited and lacks relevant experience and information to conduct benchmarking.

R05	Regulatory risk	The uncertainty about how the regulatory environment may evolve with regard to green buildings is a prime concern for developers as changes in regulations could lead to significant punitive damages if standards were not met.
R06	Legislative risk	Legislative risk refers to the risk that a change in the tax and incentives could affect a project. Incentives are not uniform and tend to change over time.
R07	Warranty risk	Warranty risk arises when a contract is not performed as promised. The current procurement contracts may lack the warranty in delivering the expected improvements.
R08	Market risk	Market risk occurs when developers are unable to articulate green building benefit to the prospective clients and fail to attain the anticipated market value.
R09	Industry risk	Green building knowledge may not be equally spread among project players within the construction industry, leading to the lack of a consensus on the green building standards and knowledge.
R10	Delay in project completion	Delay is a common problem to all types of construction projects, including green retrofit projects. In retrofit, measures that minimize disturbance to occupants and disruption to existing building operations should be considered in the schedule planning.
R11	Productivity risk	Green retrofit projects require a peculiar set of knowledge and management skills that are different from traditional retrofits. The lack of such knowledge and management skills is likely to result in low project productivity.
R12	Manpower supply and availability	Green retrofit projects require skilled workers to handle specialized designs and features. However, there is a significant lack of competent and experienced workforce in the green construction industry. Also, Singapore's Ministry of Manpower (MOM) recently increased the foreigner worker levies and cut the foreign worker quotas, which would aggravate the unavailability of competent manpower.
R13	Material supply and availability	In Singapore, the construction material supply, including green material, depends on imports. Foreign governments' restrictions on material exports would aggravate the problems of material supply and availability.
R14	Team performance risk	Being a comparatively new industry, some owners have to approach green project with an inexperienced team. Others may encounter team members who are uncooperative, as they do not understand the rationale behind green buildings.
R15	Reliability and accuracy of benchmark	Many building owners had little information of their buildings' energy saving potentials and lacked energy performance indicators for measurement and verification of energy savings. Thus, the owners would not be able to benchmark themselves for improvement.
R16	Quality risk	Occasionally the green technology and product innovations were not properly field tested or untested and were of inferior quality, thus failing to meet the expectation.
R17	Pre-retrofit tenants' cooperation risk	Pre-retrofit refers to the state prior to the completion of a retrofit project. Retrofit is usually performed while existing operations are running. Tenants may not appreciate the benefits and are uncooperative for fear of losing commercial profits during the retrofit process.
R18	Post-retrofit tenants' cooperation risk	Post-retrofit refers to the state after retrofit completion. One of the post-retrofit challenges faced by the owner is the whim of the tenants. To maintain the benefits after the retrofit, equipment has to operate at its best efficiency, requiring tenants' continuous cooperation.
R19	Different concerns of stakeholders	Because of the fragmentation nature of the construction industry, different stakeholders tend to have different concerns or conflicting objectives. The uncertainty in stakeholders' concerns represents a barrier to the adoption of green technology and may threaten objectives of green retrofit projects.
R20	Lack of streamlined tools and processes	There is a lack of streamlined tools and processes guideline set for companies to follow, which is also a challenge in the green building construction industry in Singapore. The risk could be magnified with the knowledge gap and lack of experience of design participants.

METHOD

Data collection and presentation

A questionnaire survey was performed to investigate the criticalities and mitigation measures of risks in green retrofit projects in Singapore. The literature review

supported developing a preliminary questionnaire. A pilot study was conducted with three professionals through face-to-face interviews to solicit comments on the readability, comprehensiveness, and accuracy of the questionnaire. Based on their comments, new risk mitigation measures were added, revisions were made to improve the readability and accuracy of the statement of the risks and mitigation measures, and footnotes were added to explain the terminologies used. The finalized questionnaire included the questions meant to profile the firms and respondents. Additionally, the 20 risks were presented in the questionnaire, and the respondents were requested to assess the likelihood and impact of each risk in traditional and green retrofit projects, respectively. Moreover, the respondents were asked to answer whether they agreed or disagreed with the 37 risk mitigation measures for the 20 risks, using a five-point scale (1=very disagree; 3=medium; and 5=very agree). In addition, post-survey interviews were carried out with five of the respondents, in order to collect the rationale behind their ratings to support the survey results.

A list of professionals certified with the Green Mark Professional and Green Mark Manager Schemes was obtained from the BCA, and served as the sampling frame. A total of 145 questionnaires were randomly sent out, and 30 responses were received. The response rate was 21%, consistent with the norm of 20%-30% with most questionnaire surveys in construction research (Akintoye 2000). Although the sample size was not large, statistical analysis could still be performed because the central limit theorem holds true when the sample size is no less than 30 (Ott and Longnecker 2008). In addition, the sample size of this study was also comparable with previous studies relating to risk management or sustainable construction [e.g., 34 in Hwang *et al.* (2014); 33 in Zhao *et al.* (2013); and 17 in Wu and Low (2012)].

The 30 respondents had an average of 13.2 years' experience in retrofit projects and an average of 4.4 years in green retrofit projects. 53% of the respondents possessed over 10 years of experience in retrofits, whilst 63% had more than 4 years of experience in green retrofits, which was reasonable because the 2nd Green Building Masterplan focusing on green retrofits was launched in 2009. In addition, the respondents were from 10 consultancy firms (33%), six developers (20%), six facility management firms (20%), five ESCOs (17%), as well as three construction firms (10%).

Risk indices

The respondents were asked to rate the likelihood of occurrence (LO) and magnitude of impact (MI) of each risk. As the evaluation of risk criticality (RC) is complex and vague, qualitative linguistic terms are unavoidable (Wang *et al.* 2004). The LO was rated according to a five-point scale: 1 = rarely ($LO < 20\%$); 2 = somewhat likely ($20\% \leq LO < 40\%$); 3 = likely ($40\% \leq LO < 60\%$); 4 = very likely ($60\% \leq LO < 80\%$); and 5 = almost definite ($LO > 80\%$). The MI was evaluated using another five-point scale: 1 = very small; 2 = small; 3 = medium; 4 = large; and 5 = very large. The LO and MI of each risk can be calculated using equation (1) and (2), respectively.

$$LO^i = \frac{1}{n} \sum_{j=1}^n LO_j^i \quad (1)$$

$$MI^i = \frac{1}{n} \sum_{j=1}^n MI_j^i \quad (2)$$

where n = the number of the respondents; LO^i = the likelihood of occurrence of risk i ; LO_j^i = the likelihood of occurrence of risk i by respondent j ; MI^i = the magnitude of impact of risk i ; and MI_j^i = the magnitude of impact of risk i by respondent j . Thus, the

LO and MI of each risk are actually the mean scores assigned by the respondents. This study adopted a RC index to evaluate the criticality of each risk. RC has been widely recognized as the function of the LO and MI (Wu *et al.* 2013; Zhao *et al.* 2013). Hence, the RC of a risk can be computed as follows:

$$RC_j^i = LO_j^i \times MI_j^i \quad (3)$$

$$RC^i = \frac{1}{n} \sum_{j=1}^n RC_j^i \quad (4)$$

where n = the number of the respondents; RC_j^i = the risk criticality of the risk i by respondent j ; and RC^i = the risk criticality of risk i . Thus, RC is on a full scale of 25.

RESULTS AND DISCUSSIONS

Risk ranking in green retrofit projects

Using Equations (1)-(4), this study calculated the LO, MI and RC values of each risk, as indicated in Table 2. According to the RC values, the risks were ranked. The top five critical risks are discussed as follows. In the risk ranking, “*post-retrofit tenants’ cooperation risk*” occupied the top position, suggesting that tenants were likely to be uncooperative after the green retrofit completion. Without tenants’ cooperation, the energy saving technology would not be used at the best efficiency and all the potential benefits would not be secured. Consequently, the owner would not have sufficient evidence to demonstrate the energy savings to the BCA, and may not be eligible for the financial incentives under the GMIS-EBP or BREEF Scheme. In addition, the BCA re-assess the certified Green Mark buildings every three years (BCA 2014b). The lack of tenants’ cooperation would make the building fail in the Green Mark re-assessment.

“*Regulatory risk*” was ranked second. In Singapore, the regulatory environment relating to green building has been evolving in the past 10 years. The Green Mark Scheme became mandatory when the Building Control (Environmental Sustainability) Regulations were enacted in 2008. After December 2010, all new buildings had to comply with a higher Green Mark standard. This required an additional 10% in energy savings and the minimum standard was also 28% higher than that released in 2005.

“*Market risk*” received the third position. The rationale behind this high RC was collected from the post-survey interviews. In the property market, most practitioners lacked relevant knowledge on green technologies and may find it difficult to clearly express the possible benefits to the clients. Hence, the owner was not likely to ensure the expected market value. Also, many tenants tended not to relate green technologies with improved quality of life, and held an idea that the costs of green retrofits were transferred to their rent.

“*Financial risk*” was ranked fourth. Although Singapore’s government provided various financial incentives schemes, such as the GMIS-EB, the GMIS-EBP and the BREEF Schemes, they would not significantly assist the building owners financially because of the uncertainty in receiving the cash incentives. In addition, the cash incentive in the GMIS-EB has expired with effect from 28 April 2014 because the funds for the cash incentives have been fully committed. Moreover, the S\$50 million GMIS-EBP is only applicable to SME tenants and building owners, and building owners with at least 30% of its tenants who are SMEs.

“*Pre-retrofit tenants’ cooperation risk*” was the fifth most critical risk. This risk was perceived impactful as the green retrofits are usually conducted with the tenants’

operation going on. The post-survey interviewees indicated that it was a challenge to obtain the tenants' cooperation because most of them believed that green retrofitting was not necessary and the works inevitably impacted their business. These findings echoed the viewpoint of Miller and Buys (2008) that tenants tended to view retrofitting works to be disruptive.

Table 2: Comparison between traditional and green retrofit projects in Singapore

Code	Traditional				Green				Paired t-test	
	LO	MI	RC	Rank	LO	MI	RC	Rank	Difference	p-value
R01	2.63	3.50	9.20	3	3.80	4.37	16.83	4	7.63	0.000*
R02	2.73	2.73	7.97	11	3.63	3.73	13.50	11	5.53	0.000*
R03	2.07	2.73	6.90	18	3.57	4.33	11.83	15	4.93	0.000*
R04	2.03	2.90	5.40	20	3.80	3.87	10.73	16	5.33	0.000*
R05	2.87	3.13	10.73	2	3.70	4.27	17.77	2	7.04	0.000*
R06	2.13	2.87	7.47	15	3.80	3.87	10.07	18	2.60	0.000*
R07	2.33	2.47	7.30	17	4.40	3.47	10.13	17	2.83	0.001*
R08	2.93	3.30	9.10	4	3.87	4.03	17.00	3	7.90	0.000*
R09	3.10	2.83	8.40	6	2.97	3.93	13.00	13	4.60	0.000*
R10	2.43	2.97	8.17	10	3.53	3.77	12.17	14	4.00	0.000*
R11	2.70	3.43	8.33	7	2.73	3.20	9.43	20	1.10	0.065
R12	2.73	2.50	7.60	14	2.73	3.67	13.30	12	5.70	0.000*
R13	2.27	3.73	6.03	19	4.13	3.90	15.30	7	9.27	0.000*
R14	2.57	3.50	7.40	16	2.57	4.03	14.40	10	7.00	0.000*
R15	2.90	3.20	9.00	5	2.97	3.80	14.47	9	5.47	0.000*
R16	2.60	3.13	8.23	8	4.17	4.10	15.20	8	6.97	0.000*
R17	2.70	2.70	7.90	12	3.30	4.17	15.90	5	8.00	0.000*
R18	3.00	3.33	7.77	13	3.30	4.30	18.97	1	11.20	0.000*
R19	3.20	3.03	11.00	1	2.87	3.97	15.37	6	4.37	0.000*
R20	2.83	2.57	8.23	9	3.97	3.30	9.93	19	1.70	0.008*

* The paired t-test result is significant at the 0.05 significance level.

The Spearman rank correlation coefficient is 0.408 (p-value=0.075)

Risk criticalities: Traditional vs. green retrofit projects

The respondents were also requested to rate the LO and MI of the 20 risks based on their experience in traditional retrofit projects in Singapore. Thus, the RC values were compared between traditional and green retrofit projects (Table 2). The paired t-test results showed that p-values of 19 risks were less than 0.05, indicating significant differences in RC values between traditional and green retrofit projects. The RC values of these 19 risks in green retrofit projects were significantly higher than those in traditional retrofit projects.

The differences in the RCs of “pre-retrofit tenants’ cooperation risk” and “post-retrofit tenants’ cooperation risk” between the two groups were great. It is an arduous task to manage tenants to main the benefits brought by the green retrofits, as a post-survey interviewee indicated. In traditional retrofit projects, the building owners do not have to demonstrate the evidence of energy savings, so the cooperation of tenants is not recognized as crucial.

“Material supply and availability” also received a low risk rank in the traditional group, and the second largest difference in RCs between the two groups. The post-survey interviewees expressed their struggles to search for green materials and were unaware of the available resources in the market, while the common materials are more widely available and known.

The difference in the RCs of “market risk” was the fourth largest. This was possibly because the real estate agents and investors were not clear about the green building benefits. The buildings with Green Mark Platinum usually experience a noticeable

increase in the sale price premiums, compared to those at the Green Mark Certified level (WorldGBC 2013). The high price premiums tend to make green retrofit buildings unattractive to the potential investors (Durmus-Pedini and Ashuri 2010).

“*Financial risk*” received the fifth greatest difference in RCs, although it was ranked high in both groups. Compared with traditional retrofitting, green retrofitting involves investing in energy-saving equipment and technologies, thus having higher upfront costs. Also, the development of an accurate cash flow forecast relies on current knowledge and past experience. However, most practitioners are relatively inexperienced in cost estimation of green retrofitting.

“*Regulatory risk*” was ranked second in both groups, but the RC was much higher in the green retrofitting. This was because green retrofit projects should be in compliance with both the basic regulations and those specifically related to the Green Mark Scheme.

Furthermore, the Spearman rank correlation was used to check the agreement in the risk ranking between the two groups. The correlation coefficient of 0.408 with a p-value of 0.075 suggested that there was no significant agreement in the risk ranking between the two groups.

Risk mitigation measures

The respondents were asked to rate whether they agreed or disagreed on the 37 risk mitigation measures. As Table 3 shows, 28 risks obtained significant agreement. To obtain tenants’ cooperation after the retrofits, building owners could increase tenants’ awareness of the benefits and provide incentives and rebates to the tenants, such as rental rebates. This measure has been adopted by some commercial buildings in Singapore, such as the 313@Somerset building. This practice is also consistent with the concept of the green lease. In addition, as for the mitigation measures for the pre-retrofit tenants’ cooperation risk, the respondents did not believe it was feasible to perform work outside standard working hours and arrange relocation for tenants because these two measures would increase the project cost and tenants may still be reluctant to cooperate. Thus, it is feasible to first get the tenants to understand the rationale behind the retrofit works.

To mitigate the regulatory risk, it is reasonable to hire consultants for advice, who have the experience and knowledge in managing green retrofit projects. These consultants should be registered under the Green Mark Professional Scheme.

As for the mitigation measures for the market risk, building owners could make the public aware of the possible benefits of green buildings through media, and use specific evidence to demonstrate these benefits. Previous studies have emphasized educating public through media (Durmus-Pedini and Ashuri 2010; WorldGBC 2013). However, collecting the evidence of building performance and energy saving received a higher score from the respondents, indicating that practitioners preferred real case studies to just education.

To handle the financial risk, practitioners could choose to retrofit in phases. By performing the green retrofit project in phases, the size and first cost would be noticeably lesser, and the impact on companies’ cash flow would not be great. Also, Singapore’s government has been very supportive of green retrofitting and provided several financial incentive schemes. Hence, these incentives schemes could be utilized to mitigate financial risk. These two measures received high scores from the respondents, indicating their applicability.

Table 3: Risk mitigation measures in green retrofit projects

Risk	Risk mitigation measures	Mean
R01	M1a Retrofit in stages	4.23 [§]
	M1b Share the risk with other parties by contractual agreement	3.67 [§]
	M1c Tap on government and financial incentives (e.g. GMIS-EB, GMIS-EBP, and BREEF)	4.03 [§]
R02	M2 Document building performance and savings to establish a proof of higher performance	3.60 [§]
R03	M3 Establish a performance based contract with the consultants	3.97 [§]
R04	M4a Check ESCOs' credibility with reference to the list of ESCOs provided by the government	4.07 [§]
	M4b Seek background information on the type of past projects handled by the ESCOs	3.50 [§]
R05	M5 Hire consultants for advice	3.73 [§]
R06	M6a Obtain legal advice (e.g. when drafting contract)	3.80 [§]
	M6b Clearly define the liability	3.63 [§]
R07	M7 Transfer risk to a third party (e.g. purchase insurance)	3.83 [§]
R08	M8a Educate the public on green building through use of media	3.53 [§]
	M8b Document performance and savings earned as benefit evidence	3.77 [§]
R09	M9a Educate professionals' knowledge of green building	3.27 [§]
	M9b Government to sponsor more green building courses for professionals	3.30
R10	M10a Adopt technologies (e.g. BIM) to manage projects	3.00
	M10b Set attainable milestones and monitor them regularly. If necessary, expedite the project	3.80 [§]
	M10c Understand and set reasonable buffer time	3.73 [§]
R11	M11 Implement good resource scheduling and planning to maximize productivity	3.80 [§]
R12	M12a Increase the usage of automation and machinery	2.90
	M12b Change Singaporean mindsets and encourage them to take up the job	2.60
R13	M13a Procure materials which are manufactured and available in either Singapore or the neighbouring countries	2.60
	M13b Carefully schedule material supplies	3.73 [§]
	M13c Industry institutions and government to provide a portal or list of green materials available	3.93 [§]
	M13d Obtain government support and invest in green material and technology research and development	3.80 [§]
R14	M14a Improve team members communication and integration	3.43 [§]
	M14b Select the Design & Build delivery method	3.13
R15	M15 Prepare a "knowledge portal" for historical data and lesson learnt to be recorded	3.70 [§]
R16	M16a Use tested and certified green materials	3.50 [§]
	M16b Conduct routine checks to ensure the desired level of workmanship are met	3.37
R17	M17a Perform retrofit work outside standard working hours	2.83
	M17b Arrange relocation for the tenants	2.97
	M17c Explain the rationale for retrofitting existing building to green building	3.57 [§]
R18	M18a Increase awareness of the benefits of retrofitting existing building to green building	3.50 [§]
	M18b Provide incentives and rebates to the tenants (e.g. rental rebate)	3.97 [§]
R19	M19 Engage in the Design & Build delivery method	3.27 [§]
R20	M20 Government to sponsor more green building research	3.33 [§]

* The one-sample t-test result is significant at the 0.05 significance level.

To integrate various stakeholders, Design and Build (DB), as an integration delivery method, is a viable solution to improve communication and minimize alienating any stakeholder base (Kibert 2012). This is because DB allows early discipline integration (Xia and Chan 2011), and thus various stakeholders' concerns can be put across.

Moreover, to ensure the material supply and availability, a portal or list of green materials available can be helpful because post-survey interviewees revealed difficulties in searching for suitable green materials available in the market. A careful schedule of material supply is also reasonable to handle this risk. Another approach, with agreement from the respondents, is to develop green materials through research projects funded by the government, thus reducing Singapore's dependence on imports of green materials.

Furthermore, to ensure the quality of green retrofit projects, the tested and certified green materials should be used. However, it was not feasible to conduct routine check, as revealed by its non-significant score. This was not surprising as routine checks would not be able to reduce “green washing”.

CONCLUSIONS

The objectives of this study are to (1) identify the potential risks in green retrofit projects in Singapore; (2) analyse their risk criticalities; (3) compare the risk criticalities between traditional and green retrofit projects; and (4) provide mitigation measures for the critical risks. Quantitative and qualitative data were elicited from a questionnaire survey and interviews. The analysis results showed that the top five risks in the ranking were: “post-retrofit tenants’ cooperation risk”, “regulatory risk”, “market risk”, “financial risk”, “pre-retrofit tenants’ cooperation risk”. In addition, 19 risks received significantly higher RC scores in green retrofit projects than in traditional retrofit projects. Furthermore, 28 risk mitigation measures obtained significant agreement from the respondents.

Although the objectives were achieved, there were some limitations to the conclusions that may be drawn from the results. First, the RC index proposed in this study was subjective and could be influenced by the experience and risk attitude of the respondents. Nonetheless, many risk management studies indicated that most risk management practices in the construction industry depended on experience and subjective judgments (Thevendran and Mawdesley 2004; Zhao *et al.* 2014a). Second, as the sample size in this study was small, one should be cautious when the analysis results are interpreted and generalized. Also, the findings from this study were well interpreted in the context of Singapore, which may be different from the context of other countries. Nonetheless, this study still provides an in-depth understanding of the risk criticalities and the mitigation measures in green retrofit projects in Singapore for both practitioners and researchers. Practitioners can customize their own list of critical risks in green retrofit projects based on the risk identification in this study. In addition, because Singapore has been recognized as a leader in advocating sustainability in the building and construction industry with its up-to-date and efficient green strategies and initiatives (WorldGBC 2013), the implications of this study can also be helpful and useful to the practitioners in other countries, where green building or retrofit projects are advocated.

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THE INFLUENCE OF CRITICAL INFRASTRUCTURE INTERDEPENDENCIES ON POST-DISASTER RECONSTRUCTION: ELEMENTS OF INFRASTRUCTURE INTERDEPENDENCY THAT IMPEDE THE POST-DISASTER RECOVERY EFFORT

Erica Mulowayi¹, Vaughan Coffey², Jonathan Bunker³ and Bambang Trigunarsiah⁴

^{1, 2 and 3}Department of Civil Engineering and Built Environment, Queensland University of Technology, Queensland, Australia

⁴King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia

The importance of developing effective disaster management strategies has significantly grown as the world continues to be confronted with unprecedented disastrous events. Factors such as climate instability, recent urbanization along with rapid population growth in many cities around the world have unwittingly exacerbated the risks of potential disasters, leaving a large number of people and infrastructure exposed to new forms of threats from natural disasters such as flooding, cyclones, and earthquakes. With disasters on the rise, effective recovery planning of the built environment is becoming imperative as it is not only closely related to the well-being and essential functioning of society, but it also requires significant financial commitment. In the built environment context, post-disaster reconstruction focuses essentially on the repair and reconstruction of physical infrastructures. The reconstruction and rehabilitation efforts are generally performed in the form of collaborative partnerships that involve multiple organisations, enabling the restoration of interdependencies that exist between infrastructure systems such as energy, water (including wastewater), transport, and telecommunication systems. These interdependencies are major determinants of vulnerabilities and risks encountered by critical infrastructures and therefore have significant implications for post-disaster recovery. When disrupted by natural disasters, such interdependencies have the potential to promote the propagation of failures between critical infrastructures at various levels, and thus can have dire consequences on reconstruction activities. This paper outlines the results of a pilot study on how elements of infrastructure interdependencies have the potential to impede the post-disaster recovery effort. Using a set of unstructured interview questionnaires, plausible arguments provided by seven respondents revealed that during post-disaster recovery, critical infrastructures are mutually dependent on each other's uninterrupted availability, both physically and through a host of information and communication technologies. Major disruption to their physical and cyber interdependencies could lead to cascading failures, which could delay the recovery effort. Thus, the existing interrelationship between critical infrastructures requires that the entire interconnected network be considered when managing reconstruction activities during the post-disaster recovery period.

Keywords: post-disaster recovery, critical infrastructure, infrastructure interdependency.

¹ erica.mulowayi@hdr.qut.edu.au

INTRODUCTION

The financial and emotional burden of natural disasters is expected to increase in the coming years (World Bank, 2011). Factors such as urbanization and environmental degradation, as well as climate instability are major contributors to the severity and the rate at which natural disasters occur since the 1980s (World Bank, 2011). Despite all of the mitigation and preparedness measures taken in advance, and which have partially succeeded in few cases, the occurrence of natural disasters and their consequences in the built environment are almost inevitable. Therefore, there is increasing recognition that the reconstruction process can contribute to reduce the risk of damage from future disasters, even if the sole reconstruction of the built environment will not eliminate the broad ranging consequences of natural disasters (Amaratunga and Haigh, 2011). Thus, it is during the post-disaster recovery period that disaster vulnerabilities which appear mainly in the forms of economic, social, environmental and physical variables need to be minimized (Australian Government, 2013 ; Bureau of Transport Economic, 2001; Chang *et al.*, 2014).

Major disasters generally require substantial efforts to rebuild physical infrastructure and recover from personal loss (Amaratunga and Haigh, 2011). The impact of natural disasters can have long-lasting implications for the national development of a country as they can impinge development efforts and drain economic resources. This is primarily due to the disabled functioning of critical infrastructures, which are essential enablers to economic and societal living conditions (De Bruijne and Van Eeten, 2007; Moteff and Parfomak, 2004). All developed societies, to a large extent, rely on the constant operation of a set of vital infrastructure systems such as energy, transport, water including sanitation, as well as information and communication technologies (ICT). The incapacitation or destruction of such infrastructure systems would have a debilitating impact on national security, economic security, and the public health and safety of communities (De Bruijne and Van Eeten, 2007; Moteff and Parfomak, 2004). Disabled critical infrastructures can exacerbate poverty, disrupt large industry as well as small businesses activities, and quite often suppress vital lifelines responsible for economic activity and service delivery (Canterbury Earthquake Recovery Authority, 2012; Hyogo framework, 2005). Given these realities, it is indispensable to develop a comprehensive approach for the effective reconstruction of interdependent critical infrastructures.

Analysts and decision makers have recently started to recognize that critical infrastructure systems have become highly interconnected and mutually dependent on each other's uninterrupted availability, both physically and through a host of information and communication technologies (Dudenhoeffer, Permann, and Manic, 2006; O'Rourke, 2007). When disrupted by natural disasters, such interdependencies have the potential to promote the propagation of failures between critical infrastructures at various levels, having dire consequences on reconstruction activities (Dueñas-Osorio and Vemuru, 2009). In this context, infrastructure interdependency refers to the reciprocal influence or relationship that exists between two or more infrastructures, through which the condition of one infrastructure affects the condition of the other infrastructure (Dudenhoeffer, *et al.*, 2006; O'Rourke, 2007). Under normal working conditions, the relationship is apparent when critical infrastructures depend on the inputs and outputs of services they share between each other (O'Rourke, 2007; Rinaldi, Peerenboom, and Kelly, 2001). For instance, in most cases, without electricity, a variety of other critical services will also fail during the post-disaster recovery period. Energy systems provide power for switches and to operate ICT

networks. Water and sanitation systems are dependent on electricity to run pumps and control systems, as well as to generate petroleum fuels for transportation of repair and maintenance personnel. Similarly, ICT systems provide network services (including information and telecommunication services) necessary for the operation and supervision of electrical networks. Additionally, energy requires water for cooling and to reduce emissions. Transport infrastructure systems provide accessibility to other infrastructure operators, recovery crews and the logistics chain during the post-disaster recovery period, and are in turn dependent upon electrical and ICT systems as well as drainage systems.

It is indisputable that infrastructure interdependencies have always been acknowledged by many industries. However, the real challenge is to incorporate and prioritise these interdependencies during the reconstruction period to prevent existing damage from escalating and resulting in additional damage, which could hinder the post-disaster recovery activities. Therefore, in order to develop robust infrastructure protection strategies after disasters, it is important to identify and understand the overall behaviour as well as the inherent vulnerabilities of these interdependent systems during the recovery period. This paper contributes towards an understanding of the risks that interdependencies pose to the post-disaster reconstruction of critical infrastructures. The paper also examines the fundamental roles that interdependency's dimensions including the types and degrees of interdependencies play in impeding post-disaster recovery effort.

CRITICAL INFRASTRUCTURES

One of the main challenges in overcoming the damaging effects of critical infrastructure interdependencies on post-disaster recovery is to understand the meaning of the concept of interdependency itself. Additionally, critical infrastructures being large complex systems, very often made of large collections of interacting parts and entities, understanding and preventing the propagation of failure due to interdependency remains a major technical challenge for the construction industry (Alesch, 2005; Dueñas-Osorio and Vemuru, 2009). To a large extent, targeting infrastructure interdependencies during post-disaster recovery requires an understanding of the dynamics and characteristics that underline not only the individual functioning of critical infrastructures, but also the linkage between them. Conscious of their criticality, several organisations around the world have been seeking to manage infrastructures and reduce the impact of their failures on the well-being of society (Canterbury Earthquake Recovery Authority, 2012; Hyogo framework, 2005). Infrastructures owners have recognised the need for clear identification of their assets' criticality in order to know exactly which assets to protect, how well to manage them as well as how to prioritise the reconstruction process. The list of critical infrastructures varies across countries and changes over time. In 1996, for example, US President Clinton signed the Executive Order 13010, establishing the President's Commission on Critical Infrastructure Protection (PCCIP) (Clinton, 1996). This Executive Order (E.O.) listed and classified critical infrastructures according to their national importance. These critical infrastructures included:

- Telecommunications;
- Electrical power systems;
- Gas and oil storage and transportation;

- Banking and finance;
- Water supply systems;
- Emergency services (including medical, police, fire, and rescue), and
- Continuity of government (Clinton, 1996).

In 2004, the Information Analysis and Infrastructure Protection Directorate (IAIPD) provided a much broader list with approximately 1,700 infrastructures considered to be critical (Moteff and Parfomak, 2004). Several infrastructures that were identified were not listed in previous reports. Nuclear power plants, for example, have recently been considered to be a critical infrastructure in some countries; while they are still non-existent in others (Moteff and Parfomak, 2004; Partnership, 2006). The variation in number of critical infrastructures over time is mainly due to the ever evolving influence that technological, economical and geo-political factors have on public safety (Australian Government, 2012). Nevertheless, the scope of this research is limited to critical infrastructures that predominantly form the resource pillars on which the global security and prosperity of a country such as Australia stands. As mentioned earlier, these critical infrastructures vary in numbers but are essentially limited to energy (including electric power), transport (including roads and railway systems), water supply (including sanitation), and Information and Communication Technology (ICT) systems (Australian Government, 2012 ; Bureau of Transport Economic, 2001).

As much as these infrastructures are considered to be critical, some are more critical than others during post-disaster recovery, and within the same infrastructure, various elements can be more critical than others, either because failures due to interdependency have minimal impact on them, or because failure of one infrastructure does not preclude the other to function (Rinaldi, *et al.*, 2001). Energy and ICT systems for example, are considered as high priority systems during recovery as they provide services directly to most infrastructures, unlike water systems from which other infrastructures could possibly abstain, depending on the circumstances. However, this does not exclude the fact that both potable water and wastewater evacuation and treatment are fundamental to the well-being of the community. In many ways, water is essential to minimise the risk of untreated effluents from contaminating water systems where humans come into contact, especially after floods and cyclones. The criticality of infrastructures during recovery depends to a large extent on the amount of services needed not only by the local community but also by other dependent infrastructures in order to recover quickly from natural disasters. In a series of recent interviews conducted in Queensland, Australia, as part of this study, five out of seven infrastructure' owners rated ICT as being the most critical infrastructure during the recovery period as the inoperability of such systems would inevitably hinder the recovery efforts of not only the dependent critical infrastructures but also the recovery crews involved in the reconstruction process. Being unable to communicate with recovery crews or other community members was considered by respondents as being the worst case scenario that could be encountered during and after disasters. Only two respondents rated energy and transport systems as being the second most critical after ICT systems. Having constant electricity and available access and mobility (through roads, bridges or rails) to reach damaged infrastructure was also considered indispensable during recovery. Nonetheless, when taking these factors into consideration, it appears evident that securing a unique infrastructure,

isolated from all other interdependent infrastructures has become increasingly inefficient, particularly during post-disaster recovery.

ELEMENTS OF CRITICAL INFRASTRUCTURE INTERDEPENDENCIES WHICH AFFECT POST-DISASTER RECOVERY

Interdependencies are generally driven by the need to maintain interactions between critical infrastructure, in order to deliver efficient services that are transmitted both physically and through a host of information and communication technologies. Disruption of critical infrastructures due to interdependencies generally falls into two categories: physical disruptions (which may correspond to shortage of supply/consumption/production of an asset) and cyber disruptions (which may correspond to electronic, radio-frequency, or computer-based attacks, to name a few). It was by investigating these emergent behaviours of critical infrastructures that several researchers, including Rinaldi *et al.* (2001), defined the six dimensional characteristics of interdependency as followed:

- Types of interdependency;
- Coupling and response behavior (or degree of interdependency);
- Infrastructure characteristics and environment;
- The state of operation of infrastructures; and
- The types of failures (Buldyrev, Parshani, Paul, Stanley, and Havlin, 2010; Dudenhoefter *et al.*, 2007; O'Rourke, 2007; Setola, Bologna, Casalicchio, and Masucci, 2009).

This paper will mainly focus on the challenges from the types of interdependencies as well as the extent or degree to which these interdependencies occur.

Challenges due to types of interdependencies during post-disaster recovery

In the interview questionnaires that were tested during the pilot study, the types of interdependency were depicted according to the nature and sort of interaction that exist between critical infrastructures through the sharing of physical supplies and commodities (physical interdependency), virtual information (cyber interdependency), the same geographical location (geographical interdependency) as well as the same legislation and public opinion (logical interdependency). These classifications were performed using key concepts and sub-concepts derived from the notion of interdependency described in various literatures (O'Rourke, 2007; Rinaldi, *et al.*, 2001).

The results revealed that during post-disaster recovery, geographical interdependency is considered to be almost an integral part of physical interdependency. Logically, to be physically interdependent, critical infrastructures need to be somehow geographically interdependent (within the same location, region or country etc.), even though the reverse is not obvious. Physical interdependency results from the exchange of services between two or more critical infrastructures (O'Rourke, 2007; Rinaldi, *et al.*, 2001). The change in condition from one infrastructure could have serious impact on the functioning of the other infrastructure. Geographical interdependency on the other hand, results from the influence that a natural disaster (or external cause) such as flood can have on critical infrastructures located in close proximity to one another, creating simultaneous disturbance in the state of interdependent infrastructures

(O'Rourke, 2007; Rinaldi, *et al.*, 2001). In this case, the change of condition of one critical infrastructure does not affect the operation of the other infrastructure. Thus, critical infrastructures that are geographically interdependent are not necessarily physically interdependent. Nevertheless, general managers responded collectively that during post-disaster recovery, physical interdependencies are usually restored first, regardless of the location of the infrastructure. This is why in this research the two types of interdependencies have essentially been reconceptualised and examined within the physical interdependency facet of critical infrastructures.

One of the main issues with regards to physical interdependency that was raised by general managers and risk practitioners from transport industries was the necessity of having inexhaustible resources available in order for infrastructures to continue to operate. Therefore to remain physically interdependent, the amount of shared services between critical infrastructures needs to be constantly available. Resource availability in a sense is also an indication of the performance of a critical infrastructure during post-disaster recovery. This anticipation that an infrastructure system will still remain operational and continue to provide resources to another infrastructure, allowing it to operate during post-disaster recovery, requires a certain level of reliability to be established between interdependent infrastructures and their organisations as well (Kapur, 2014). Infrastructure reliability in this context refers to the probability that resources or services will still be available to facilitate the sharing process between critical infrastructures during post-disaster recovery (Kapur, 2014). In this case, reliability is measured in function of the availability of resources and represents the probability of an infrastructure to continuously produce resources during the recovery period. The fewer available resources an infrastructure produces during the recovery period, the less reliable it is considered to be. Analysis of data also revealed that the challenge in maintaining physical interdependency is not only limited to resources availability and infrastructure reliability but it also requires the effective transfer of resources from one infrastructure to another. If access to the distribution channels from which resources are conveyed and delivered from one infrastructure to another are disrupted during recovery, physical interdependency would also cease to exist, regardless of the resources' availability or of the infrastructures' reliability. Therefore availability, reliability, and transferability or deliverability of resources are considered to be essential attributes or main contributors to physical interdependency. If any of the above conditions is not satisfied, then the physical interdependency will fail.

Although cyber interdependency is created through the share of virtual information and communication between critical infrastructures during recovery, most critical infrastructures possess a supervisory control and data acquisition (SCADA) system, which allow them to individually operate. The main role of ICT in regards to interdependencies with other critical infrastructures is to provide telecommunications services necessary for the supervision, control and evaluation of the state of these systems at any given time (Ventura, García, and Martí, 2010). Therefore availability, reliability, and transferability are also essential conditions in attaining cyber interdependency. In the same way that physical interdependency will fail if these conditions are not reached, cyber interdependency would also be inexistent. Logical interdependencies, in contrast, do not rely on these attributes as they are tailored by human decisions or factors including procedures and policies that shape a specific region. Logical interdependency is also associated to the conformity of critical infrastructures to the laws, rules and regulations of their organisations (Dudenhoeffer, *et al.*, 2006; O'Rourke, 2007). An example of logical interdependency can be observed

after a road closure following a natural disaster, which destroyed a section of a motorway. The decision of closing the road could necessitate an increase in traffic on a parallel railway due to a large number of persons and goods travelling by railway instead of using personal vehicle, bus or truck. The increase in rail traffic volume would require more electric power to sustain the traffic flow, which in turn could possibly generate an overload usage of the electrical network and possibly lead to a failure of the latter. Thus, logical interdependency (based on human decisions) influences all other types of interdependencies and can hinder the reconstruction or repair of critical infrastructures during post-disaster recovery.

Challenges due to degrees of interdependencies during post-disaster recovery

The degree of interdependency denotes the extent (or intensity, strength, and amplitude), to which interdependencies between critical infrastructures exist and are manifest (Dudenhoeffer, *et al.*, 2006; O'Rourke, 2007). This sort of interdependency is generally perceived in the reciprocal influence exerted between critical infrastructures, which is also observed through the mutual exchange of services that occur among them. The strength of the interrelationships between critical infrastructures varies considerably. Some interdependencies are loose and thus relatively flexible, whereas others are tight, leaving little or no flexibility for the system to respond to changing conditions or failures due to natural disasters (O'Rourke, 2007; Rinaldi, *et al.*, 2001). Loose interdependency implies that infrastructures are relatively interdependent of each other at a certain level, and thus the state of one is weakly correlated to the state of the other infrastructure (Ventura, *et al.*, 2010). Tight interdependency means that infrastructures are highly dependent on one another (Rinaldi, *et al.*, 2001). For instance, nineteen percent of respondents amongst general managers agreed that energy and ICT systems induce high degree of interdependencies to other critical infrastructures systems as they provide services, which are crucial to the functioning of these infrastructures at all time. Railway systems for example are strongly dependent on electric power to function, while energy systems are loosely dependent on railways. Although railway systems provide access and transport for natural gas derivatives and energy utilities, disturbance of rails does not necessarily induce the disruption of electric power.

Disturbances tend to propagate rapidly both through and across tightly coupled infrastructures. According to Rijpma (1997) and Weick, Sutcliffe, and Obstfeld (2008), tight interdependency is likely to be found with infrastructure systems that rely mostly on the use of unifiable, invariant, and time-dependant processes (Rijpma, 1997; Weick, Sutcliffe, and Obstfeld, 2008). These processes must be performed in a set sequence to avoid halting the exchange of services at one stage and restart again (Rijpma, 1997; Weick, *et al.*, 2008). Rijpma (1997) further explains that such orderly systems both increase the likelihood that tasks will be accomplished and that disturbances could easily escalate and be diffused more widely to the rest of the interdependent systems. Whereas in loosely coupled systems, the production sequence can be easily redesigned during post-disaster recovery if a disturbance occurs (Rijpma, 1997; Weick, *et al.*, 2008). Therefore, tightly coupled systems could cause greater concern for the reconstruction and repair of critical infrastructures. This is why it is essential to determine the extent to which critical infrastructures are interrelated, and in certain conditions to determine whether or not their degrees of interdependence could have an impact on their recoveries.

To determine how strong the interactions between two critical infrastructures exist during post-disaster recovery, it is necessary to determine for each infrastructure the other infrastructure that it continuously (or nearly continuously) depends on to operate normally, and also investigate the channel by which the services are delivered (from one infrastructure to the other infrastructure) (Ventura, *et al.*, 2010). Furthermore, time is another factor that indicates how strong interactions between critical infrastructures are. Time, as a measure of interaction, refers to both the frequency (how often exchanges are performed) and the duration (how long infrastructures have been dependent on each other). The latter provides an indication of how long supported infrastructures could function during post-disaster recovery if they were deprived of services coming from the supporting infrastructure (s). According to general managers and risk practitioners, a strength capability measure is used to determine the amount and the intensity of reciprocal services between infrastructures when faced with such complex interactions (Ventura, *et al.*, 2010). However in the case of simple linear interactions, considerations are generally given to determining how indirect, or direct, interdependencies between two critical infrastructures are, whether they are directly connected to one another, or indirectly coupled through one or more intervening infrastructures (Rinaldi, *et al.*, 2001). Overall temporal interaction affects any other degree of interdependency, whether the relationship was generated in the past, the present or is ongoing.

CONCLUSIONS

The preliminary results of a recent pilot study conducted in Queensland, Australia, revealed that the types of interdependencies, including physical and cyber interdependencies as well as the degree to which infrastructures interact, have the potential to impede the post-disaster recovery effort. The results also revealed that within these elements, critical factors such as resources availability, reliability and transferability can also impede the post-disaster recovery effort. The continued reliability of critical infrastructures is paramount during the post-disaster recovery period. As mentioned earlier, the escalating complexity and vulnerability of infrastructures due to their interdependencies has been evidenced in recent years by their notable failures. For instance, a large-scale power outage could affect simultaneously all the interdependent critical infrastructures. The reliable exchange of services that occurs between interconnected systems also depends on the uninterrupted functioning of these infrastructures. Supposing that interconnected infrastructures fail to achieve their intended purpose, interdependencies will be likely to cause more harm than benefits to the entire network system during recovery. In this case, there are two paradoxical effects associated to the existence or inexistence of interdependencies between critical infrastructures. On one hand, interdependencies could generate widespread cascading failures amongst critical infrastructures in the aftermath of disasters (Buldyrev, *et al.*, 2010). On the other hand, the absence of interdependencies as such, could also interrupt the functioning of the entire interdependent network. Viewed from this perspective, in a post-disaster reconstruction framework, it is crucial to maintain reliable infrastructure interdependencies to both the constancy of shared services as well as to the safety of critical infrastructures.

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INTEGRATING VALUE, RISK AND ENVIRONMENTAL MANAGEMENT AT THE STRATEGIC DEFINITION STAGE

Mohammed Alaqaad¹, Kassim Gidado and Poorang Piroozfar

School of Environment and Technology, University of Brighton, Brighton, BN2 4GJ, UK

Over the years, researchers and practitioners have argued that the integration of value Management (VM) and Risk Management (RM) in construction projects would help avoid duplication of work and deliver better value for money thereby leading to better project outcomes. Others have integrated the VM and Environmental Management (EM) to achieve the same goals. In the UK, research has shown that the lack of awareness of the environmental issues and the timing of implementing the various Project Management Systems (PMS) during the course of a construction project are the main constraints to better integration of these systems. This paper will argue that the integration of VM, RM and EM would provide better efficiencies and suggest how it could be achieved. Using desk study, the paper investigates the issues and problems surrounding the integration of PMS. It also identifies the aspects of VM, RM, and EM that could be integrated in projects using published literature. The findings at this stage form an initial frame of reference as a basis upon which a model will be developed for the complete integration of VM, RM and EM in construction projects at the early stage.

Keywords: value management, risk management, environmental management, systems integration.

INTRODUCTION

Typically, the activities that any organisation needs to manage can belong to different management systems such as risk, value and environmental management systems. The organisation can achieve the maximum efficiency at the minimum cost by managing these different systems collectively rather than separately (Bernardo, 2014). Applying this practice involves assessing the different activities in the different systems, exploring the synergy between them and finally integrating them together in a new management system, i.e. integrated management system (Orlru, 2014). Hence, the integrated system will be largely affected by the integration strategy, the integration methodology, the level of the integration, and the benefits and barriers of the integration (Bernardo, 2014).

The integration of value Management (VM) and Risk Management (RM) in construction projects has been argued to help avoid duplication of work and deliver better value for money, leading to better deliverables in projects and higher level of satisfaction. Others have argued for the integration of VM and Environmental Management (EM) to more or less achieve the same goals. To date there is no comprehensive integration model to merge and combine these three project

¹ m.alaqaad@brighton.ac.uk

management systems (PMSs). As a part of an ongoing research project this paper contends that the integration of VM, RM and EM would provide better efficiency, particularly when set up at the strategic definition stage (i.e. RIBA Stages) (RIBA Plan of Work, 2013). It also suggests how this integration can be achieved. The paper sets out to investigate the issues and problems surrounding the integration of PMSs through desk study. It also identifies integration models and explores the aspects of VM, RM, and EM that could be integrated in projects. The findings at this stage form an initial frame of reference as a basis upon which a model will be proposed – at later stages of this research once the expert opinions were gauged using corresponding methods – to help realisation of full integration of VM, RM and EM in construction projects.

INTEGRATION OF MANAGEMENT SYSTEMS

The different management systems, e.g. VM, RM, and EM can be integrated mainly using three approaches namely i) developing a new model, ii) using an existing model, or iii) merging two or more existing models (Dalling and Holt 2012). In case of adopting an existing model, one can use one of the following available models:

Wilkinson and Dale (2001) proposed a total quality model to integrate quality, environment, health and safety processes into one management system. The model earned the title total quality model as it implements a full integration between the different activities in the different management systems such that the independent systems are digested and amalgamated into a new system rather than simple merger of documentations of different systems. Furthermore, this model is based on considering effect of both integrated organisational structure and people's culture on the interplay between the resources, processes and procedures throughout different phases of the integration, as described in table 1.

Pun and Hui (2002) suggested a similar model to integrate Quality, Environment, Health and Safety (QEHS) processes into one management system. This model is built upon the synergy between the different processes involved in the integrated system, which are assumed to be interrelated. For instance, in case of QEHS, several links were found between the size of company and awareness of safety and quality management on one hand and structure of the organisation, focus of employee, leadership, safety culture and cost consideration of integration on the other hand. This model adopts the Total Quality Management (TQM) in the integration phase but adds one phase for planning the different processes and identifying the synergies and one phase after integration to train people on quality and safety culture and get them involved and finally to standardise the adopted methods.

Karapetrovic (2003) proposed the systems model to combine the benefits of the process model, which guides interconnected processes to achieve best quality, and Shewhart's Plan-Do-Study-Act (PDSA) cycle or Plan-Do-Check-Act (PDCA), deals with a single process. Therefore, the idea behind the systems model is to improve every phase of the integration by focusing on improving the efficiency of not only the collective multiple processes as a whole but also the single processes by their very individual nature. The continuous improvement of these processes can be achieved throughout the different major phases of the integrated system as indicated in table 1.

Nevertheless, it should be mentioned that the success of the integration process does not depend only on the choice of the model but also on certain key factors. These

factors rely on achieving: clear focus, common understanding of the integration structure and processes, complete implementation of the integration model, and complete implementation of the PDCA procedure (Dalling and Holt 2012). Furthermore, Ranesh *et al.* (2012a) identify four main Critical Success Factors (CSF) for effective integration:

1. Availability and adoption of appropriate integration standard.
2. Appropriate linkage between the tasks and phases of the systems.
3. Degree of integration.
4. Selection of appropriate integration techniques, e.g. brainstorming, etc.

Table 1: Available models of integration systems

Model	Main stages
Process model (Pun and Hui 2002)	<ul style="list-style-type: none"> • Planning objectives and tasks determination • Integration implementation and evaluation • Installation • Measuring results and standardizing procedure
Systems model (Karapetrovic and Jonker 2003)	<ul style="list-style-type: none"> • Goals determination • Planning and designing processes • Acquiring resources • Deploying resources • Implementing processes • Evaluating results
Total quality model (Wikinson and Dale 2001)	<ul style="list-style-type: none"> • Goals determination • Resources integration • Processes integration • Planning, controlling and implementing processes • Evaluating results and redefining goals • Continuous improvement cycles

The integration between the different management systems can be performed at different phases throughout the project. For instance, the integration can be implemented in the project's job plan through workshops and brainstorming (Abd-Karim *et al.* 2011). Ranesh *et al.* (2012a) conclude that the integrated workshops are the most accepted means of integration from the client's point of view. These workshops can help achieve integration while minimizing the cost and time compared to workshops when held individually. In addition, the integrated workshops help utilize the multidisciplinary team. In these workshops, it is vital to incorporate external experienced consultants (Ammenberg and Sundin 2005). These consultants, along with the multidisciplinary team can help to stimulate the discussion, pinpoint the appropriate links between the tasks in the different systems, find appropriate or alternative solutions, and adopt apt existing standards or modify them as needed.

Based on the aforementioned discussion, the integration of different management systems seems to be beneficial. Nevertheless, this integration can also have certain disadvantages. The advantages, disadvantages and barriers for any integration process will be discussed thoroughly in the following sections.

BENEFITS OF INTEGRATION

There are several benefits to integration between the different management systems. These benefits include saving time and resources, maximizing efficiency, facilitating the flow of information and improving the decision making process (Hiley and Paliokostas 2001, Ranesh *et al.* 2012a). The complete formal integration also promises better outcome and maximizes the savings of time and efforts through avoidance of

repeating the common tasks (Ranesh *et al.* 2012b). Moreover, the integration benefits greatly from addressing certain tasks and issues encountered in one system in light of the experiences gained through similar tasks and phases in other systems (Mootanah *et al.*, 1998). For instance, Haghnegahdar and Asgharizadeh (2008) suggest that the integration of RM and VM can help in early recognition of risk, decrease project time, and increase value. Dalling and Holt (2012) reiterate this by stating that integration is beneficial and mention that finding correlations and shared impact between the different tasks involved in the project is one of the greatest benefits for the integration. Hiley and Paliokostas (2001) argue that the benefits of integration exceed the traditional view of best value for money (VfM) to include better communication between the team members and stakeholders. In addition, clearer objectives can be defined and followed. Rajković *et al.* (2008) stress that integration provides better control of the resources compared to when individual management systems are deployed separately. Kirk (1995) highlights that the integration is beneficial from different angles including i) the benefits of the views of outside experts, ii) eye-opening to difficult-to-quantify elements, and iii) analysis of savings based on the different alternatives. Finally, Ranesh *et al.* (2012b) assert that the benefits of integration include simplifying the management records and facilitating communication and discussion between the team members and stakeholders.

BARRIERS TO INTEGRATION

Despite numerous advantages of integration, there are inevitable disadvantages and barriers that can greatly affect the integration efficacy. For instance, Hiley and Paliokostas (2001) argue that the lack of information about the exact guidelines and standards, which practitioner should follow, can be one of the biggest obstacles in integration process. In addition, integration can be hurdled by differences in two or more systems which are to be integrated, what requires different team members with different views in order to tackle the problems in more efficient ways (Hiley and Paliokostas 2001). However, having a multidisciplinary team in the same workshop might not always be beneficial. This is because integrating two systems that are somehow different and involve different phases, makes it difficult to discuss the two in the same workshop, which can result in losing the purpose or focus mainly due to lack of enough time, appropriate knowledge and/or relevant information. Therefore, there is a need for a facilitator to organise the participation at different stages of the project. This leads to another critical issue that is people involved in the integration process might not be needed all the time (Ranesh *et al.* 2012b).

Campos *et al.* (2014) suggest that a well-defined and permanent organisation structure is required to implement and follow-up the integration process. Ammenberg and Sundin (2005) affirm that integration can be affected or hindered by the available standards, driving interest, available resources, competence and information. Similarly, Dalling and Holt (2012) summarise six barriers for successful integration: 1) Lack of commitment, 2) Conflict of interests, 3) Lack of stakeholders drivers for integration, 4) Lack of standardized methods and protocol for integration, 5) Lack of information and knowledge, 6) Resistance to change.

On the other hand, Zeng *et al.* (2006) show that the main internal barriers for any successful integration include human resources, knowledge, structure and culture of the organization. In addition, the main external barriers are lack of technical standards and models, lack of legislation bodies, lack of stakeholder's interest and the institutional environment. Rajković *et al.* (2008) reiterate these barriers and add that

the complexity of the different management systems and the effort needed for integration can also hinder the integration process.

INTEGRATION BETWEEN VM AND RM SYSTEMS

The aim of the integration between value management and risk management systems is to maximize the value for money by the efficient allocation of risk. RM and VM are somehow similar in different aspects including that both i) are structured decision making tool, ii) contribute to the VfM, iii) have same processes with different focus, iv) involve the same stakeholders, v) require information sharing, and vi) use the same techniques such as brainstorming and function diagrams. The complete formal integration also pledges better outcome and maximizes saving in time, cost and effort through the avoidance of repeating the common tasks, which is common occurrence where VM and RM are considered separately (Ranesh *et al* 2012b). Moreover, the integration benefits greatly from addressing all risk issues in light of VM (Mootanah *et al.* 1998). To investigate the extent of integration between VM and RM, Ranesh *et al.* (2012b) use semi-structured interviews conducted with ten industry practitioners involved in Public Private Partnerships (PPPs) projects in Australia. The study concluded that the integration between VM and RM were never performed formally. Similarly, Hiley and Paliokostas (2001) came up with similar findings which imply that the integration between VM and RM is practiced in the built environment project in informal ways. One reason behind this formally abandoned integration can be attributed to the confusion related to the lack of knowledge of how exactly to integrate VM and RM and at which stage of the project should this be addressed (Ranesh *et al.* 2012b, Hiley and Paliokostas 2001). Therefore, to avoid any confusion, Othman (2005) proposes that the IRVM should be simple and easy to follow, otherwise the integration will be hindered and the focus will be lost. In addition Ranesh *et al.* (2012b) suggest that the participant of Integrating Risk Management and Value Management (IRVM) should be knowledgeable of not only VM or RM but also the two of them together. This is also proposed by Othman (2005) who indicates that the diversity of the team is crucial for making good decisions.

There are several approaches for integrating VM and RM. Abd-Karim *et al.* (2011) study the applicability of integration in the project's job plan through workshops and brainstorming in four infrastructure projects in the UK. The study highlighted that the efficiency of integration through the job plan and brainstorming is much better than applying only one of them. Moreover, the study identified that the efficacy of integration relies upon the time and budget constraints in addition to the project's complexity and client's requirements. Another critical element is that all the participants in the IRVM workshops should be familiar with the methods, techniques and tools used in the integration (Ranesh *et al.* 2012b). Ranesh *et al.* (2012a) identify several CSF for the implantation of IRVM including the discipline, scope, location, and time of the study as well as the involvements of the key stakeholders and the client's willingness and requirements. On the other hand, Ranesh *et al.* (2012b) identify the following six CSF for the IRVM integration: 1) Study type; 2) Study methods; 3) Study tools and techniques; 4) Selection of integration standards; 5) Effective linkage between RM tasks and VM phases; 6) Degree of integration.

Many studies have introduced clear methodologies and models for integration. For instance, Kirk (1995) presented a methodology for the complete integration between VM and RM in every stage of the project. In addition, Othman (2005) introduced Value and Risk Management Protocol (VRMP) asserting that the integration should

be performed in three main stages: i) the pre-study phase that is used to collect data and information, ii) the study phase where the objectives and alternatives are defined and evaluated, and iii) the post-study phase during which the best alternative is implemented and monitored. Mootanah *et al.* (1998) highlight that these stages are in line with the different value management phases, and therefore can be carried out simultaneously while performing VM tasks. Haghnegahdar and Asgharizadeh (2008) argue that applying integration at the early stages, e.g. briefing stage, is best practice, which leads to minimized cost and early recognition of risks and their effects on value. Chang and Liou (2005) argue that the degree of integration should not be considered arbitrarily but rather as inversely proportionately to the budget and urgency of the project. Therefore, for small budget projects, the authors propose to integrate RM into only the evaluation phase of the VM. This is an executive approach to save more time and money that is especially applicable to small projects.

Based on the aforementioned discussion, it can be concluded that the integration process is complex and requires paying careful attention to all the details of the project including its location and budget constraints.

INTEGRATION BETWEEN VM AND EM SYSTEMS

The whole life value of any project involves the identification of stakeholders, functionality, performance, cost, risk and environmental sustainability (Mootanah 2005). Zeng *et al.* (2006) examine the difficulties and barriers in integrating the environmental and occupational management systems. The study showed that the main internal barriers for any successful integration of EM include human resources, knowledge, structure and culture of the organization. Furthermore, the main external barriers are lack of technical standards and models, lack of legislation bodies, lack of stakeholder's interest and the nurturing institutional environment (Zeng *et al.* 2006). Al-Saleh and Taleb (2010) investigate the integration of VM and sustainability especially in the Gulf States. The study concluded that in most of the cases the integration is very weak. The study also identified the following reasons behind this absence or procrastination of integration in built environment projects:

- lack of infrastructure and government bodies to support the integration
- lack of skilled workforce to implement and follow-up the integration process
- lack of awareness of local regulations concerning the necessity of sustainability as a vital integral part of the project.

Al-Yami and Price (2005) also point out that the biggest obstacles on the way of full integration can be related firstly to the misinformed practitioners that sustainability is already taken care of by Value Engineering (VE) or RM and secondly to the lack of information concerning the guidelines of how to apply the integration in different projects. Al-Saleh and Taleb (2010) also point out that the lack of codes and protocols as well as time constraints can put hurdles on the way of integration. Moreover, the focus on cost reduction rather than sustainability improvement can hinder the integration significantly. Al-Yami (2006) draws attention to the fact that cost of not considering sustainability, including environmental sustainability, in fact increases due to the increased consumption of energy and raw material. Furthermore, Al-Yami (2006) suggests that the only effective way to implement sustainability is by changing the general view to focus on long-term value instead of short-term cost. Campos *et al.* (2014) assert that a well-defined and permanent organisation structure is required to implement and follow-up the integration process. Al-Yami and Price (2005) advocate

a link between VE and sustainability which can be linked in early stages of projects using an integration scheme that utilizes six stages:

- i) professional consideration of VM using experience of VE
- ii) identification and optimization of the available resources
- iii) dedication of a team for VE
- iv) finding creative solutions to achieve the project's goals in light of the available resources
- v) performing the VE study
- vi) implementing the recommendations of the VE study

Furthermore, Ammenberg and Sundin (2005) claim that integrating the EM system and design for the environment (DfE) could be achieved by adding a life-cycle perspective to the EM system.

INTEGRATING VM, RM AND EM SYSTEMS: A PROPOSAL FOR A NEW FRAME OF REFERENCE

Berawi *et al.* (2013) show that the main factors affecting the success of any building project are the time schedule of the project, completion effectiveness, efficiency of investment, security and safety, and physical and psychological comfort of the occupants. In addition, their study suggests that the main barriers to the success of a project are lack of commitment and support from management, unethical behaviour from the professionals, lack of supervision, lack of expertise in the project, and delayed implementation schedule. These factors can affect the VfM and can impose additional risks if not handled properly. This highlights the need to integrate VM, RM and EM to maximize value, minimize risk and achieve long-term sustainability. This need for integration is also stimulated from the fact that the whole life value of any project involves the identification of cost, risk and environmental sustainability (Mootanah 2005). Therefore, the integration between the value, risk and environmental management systems is expected to improve the whole life value. So far, this integration is not fully achieved. In addition, thus far no complete model has been proposed to formally establish clear guidelines for the Integrating Risk Management, Value Management and Environmental Management (IRVEM) process. This paper aims at filling this gap and laying the foundations for proposing a model for integrating VM, RM and EM systems.

The proposed model is inspired by the models, which are proposed, by Kirk (1995) and Othman (2005) for IRVM. Kirk is one of the first to propose a full implementation model for quantitative assessment and analysis of the associated risks with the different elements in each process, i.e. labour, material, duration and cost. Therefore, a probability curve can be obtained for every associated risk, which can be used to weigh the possible alternatives to choose from. Othman (2005) used the same methodology but suggested that not only risks but also value should be quantified. Hence, based on Othman's model, one needs to develop a hierarchy matrix, i.e. importance weights, for every objective. In addition, one needs to develop a decision matrix through which risks are taken into account based on their severity and likelihood whereas the alternatives are assessed based on their importance weights in the hierarchy matrix.

Adopting the same philosophy to integrate EM in RM and VM, the first step in our proposed IRVEM model is to define the hierarchy of demand i.e. the most critical elements in the integration that have the greatest impact followed by the less influencing elements. For instance, in case of considering the integration of value, risk

and environment, the first element in the hierarchy of demand is risk minimization, followed by value maximization and saving resources. The critical task here is to find the common ground to achieve most of the hierarchy of demand matrix with less resources and faster response time. In this respect, the following frame is proposed for a new integration model:

1. Pre-integration phase

- 1.1. Identify the goals
- 1.2. Identify the hierarchy of demand matrix
- 1.3. Identify the tasks related to every item in the matrix
- 1.4. Identify the resources available to every task
- 1.5. Identify the different risks associated with the different tasks
- 1.6. Identify the elements in the different tasks related to environment
- 1.7. Rank the matrix items and the associated tasks, resources, environment elements and risks according to the demand. The final rank would be considered as the importance rank multiplied by the number of associated tasks divided by the available resources

2. Integration phase

- 2.1. Link the different resources in order to maximize the value for money
- 2.2. Recalculate the hierarchy of demand matrix based on the linked and shared tasks
- 2.3. Integrate the tasks according to their rank, e.g. high-risk tasks together and high-value tasks together.
- 2.4. Deploy resources on the integrated tasks based on their rank
- 2.5. Implement processes

3. Post-integration phase

- 3.1. Evaluate outcome
- 3.2. Redefine goals
- 3.3. Re-identify the tasks, risks, resources and hierarchy of demand matrix
- 3.4. Compare the current ranks with the initial counterparts
- 3.5. Reprocess

The advantage of this model is the clarity of the phases and the tasks involved at each phase. In addition, it presents clear criteria for making the decisions about which tasks should be merged together or considered simultaneously. Interviewing expert practitioners in the field of RM, VM and EM will help shed some light on functionalising the model, its applicability and adopting any recommendations and adapting the preliminary model through professional feedback loop validation process.

CONCLUSIONS

In the UK, research has shown that the lack of awareness of the environmental issues and the timing of implementing the various Project Management Systems (PMS) during the course of a construction project are the main constraints to better integration of these systems. This paper argued that the integration of VM, RM and EM would provide better efficiencies and suggest how it could be achieved. Using desk study, the paper investigated the issues and problems surrounding the integration of PMS. It also identified the aspects of VM, RM, and EM that could be integrated in projects using published literature. The findings formed a basis upon which a framework for a new model was developed and proposed for the complete integration of VM, RM and EM in construction projects. This initial framework will be deployed at the next stage of this ongoing research project as a basis for developing a novel model to integrate VM, RM and EM. Real data will be collected and collated from different live projects and via questionnaire surveys, expert interviews and industrial expert steering/focus groups to help facilitate the approach and to mobilise the model. Through the text and content analysis, different factors, elements, barriers and facilitators of such integration will be interrogated, and effective strategies, methods

and actions will be developed to help form the model, its verification and improve its applicability, validity and reliability through a reiterative feedback loop.

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MINIMISATION OF RISK EXPOSURE AT THE PRE-PRODUCTION STAGE THROUGH THE USE OF CONTRACTOR-LED DESIGN MANAGEMENT

Seoung Wook Whang¹ and Roger Flanagan

School of Construction Management and Engineering, University of Reading, Reading, UK

Many large scale construction projects (LSPs) are designed in a collaboration between famous international architects and local design firms. Design management usually evolves as a tool at the design stage for designers and design solution. One of the special characteristics of the Korean construction environment places a duty and responsibility on the contractor to coordinate and check design information. Hence the contractor must manage and integrate diverse design information into the production process. This research considers how the design management diagram (DMD) can help as a part of the system at the pre-production stage of LSPs in Korea². The pre-production stage receives insufficient attention from the research community from the perspective of design management; it is a complex process involving interdependence, risk, and uncertainty. Through the application of a DMD from the pre-production stage, the contractor can predict and manage the design-related uncertainty during production stages. The design management factors (DMFs) were analysed by the analytic hierarchy process (AHP), and then used complexity system theory to understand the interrelationship between the causal factors. DMFs are presented as a causal loop diagram which can help the contractor to cope with design-related uncertainties at the early production phase.

Keywords: causal loop diagram, contractor-led design management, international design team, pre-production stage.

INTRODUCTION

Construction projects are being increased in size, scale, and complexity. The contractor must calculate the production cost and the time requirements, and then establish the appropriate execution strategy at an early stage. Large scale construction projects (LSPs) incorporate lots of design elements that require unique and innovative structural, mechanical, lighting, electrical, and environmental systems (Aminmansour and Moon, 2010). The complex technologies and systems with different requirements for expertise including specialist, subcontractors and suppliers more increase the project complexity. In addition, international design team involved in the design process add another layer of complexity that the contractor must manage. Such design teams are influenced by different culture, technical standards, and work processes, making design collaboration challenging. Such arrangements often results in a complex for the delivery of the design information to the contractor. This has led to project cost overruns, time overruns, and poor profitability for Korean contractors.

¹ zz026014@reading.ac.uk

² For the purpose of brevity, Korea has been used throughout the document to denote the Republic of Korea, which is South Korea.

It is very difficult for the contractor to address these complexities and uncertainties during production stage. They have to establish the appropriate production strategy and prepare a suitable implementation plan within the short period of the pre-production stage (Song *et al.*, 2009). During the pre-production stage, the time constraint means lots of critical elements are overlooked. Thus, the contractor should retain the appropriate method to manage the design information. The contractors need to convert the design information into production information. Moreover, contractors should consider the assembly of the construction team, the pre-ordering of materials, and the planning of production prior to work commencing at pre-production stage. However, contractor normally does not have their own design management team to manage the diverse and complex design information. Particularly, under multinational complex projects, contractors have suffered from the uncertainty caused by insufficient management of design information. This can directly influence rework, duration, and profit at production stage (Lopez and Peter, 2012).

Insufficient attention has been given to the effective management and use of design information at the pre-production stage. This research focuses on how design management at pre-production stage can help the contractor to recognize design-related uncertainties and prepare appropriate execution methods. The aim of this research is the establishment of a DMD from the contractor's perspective to manage the design-related uncertainty at the pre-production stage. It will be useful particularly for Korean construction enterprises working on LSPs designed by international design teams. Based on complex system and system thinking as an underlying theory, factor interdependent causal loop diagram was established as a DMD in order to understand how DMFs influence the practical production stage.

PROJECT DELIVERY IN KOREA

Large contractors who are part of a large conglomerate dominate the Korean LSP market. These large conglomerates have both moral and legal responsibility to deliver projects; they are an important part of the business and social infrastructure of Korea. The general contractor as an affiliate of a conglomerate takes a total responsibility for project delivery. Legal and statutory responsibility lies with the contractor to ensure engineering integrity of design. Legally a contractor has to review and confirm the integrity of drawings and documents along with the project supervisor before commencement of construction (Bea *et al.*, 2006; Moleg, 2014). When contractors take over a project from the architect they have to check all the design and documents, and then establish the implementation plan to manage the design-production elements. International design teams, in many cases in Korean LSPs, rely on contractors to respond quickly to unexpected problems on site, even though the initial problem may have been caused by insufficient or incorrect design information.

Almost all large contractors in Korea act as a construction manager and as a design manager on the project as well. Because there is no practical concept of a project manager in the Korean construction industry, the design management team undertakes large parts of the project manager's role. Design management team is closely interconnected with all production stages as well as influencing project productivity and performance; it is one of the main reasons that the research focused upon contractor-led design management.

Many large Korean conglomerates have diverse subsidiary companies in the construction industry such as developer, contractor, consultant, and provider of heavy equipment and construction materials as part of their business. When the large

conglomerates develop a LSP, consideration is given to different business aspects directly related with their subsidiary companies. Subsidiary companies constantly request design or material changes in order to supply a certain material or equipment which they produce or trade (Kim and Kown, 2005). At the early project stage, the contractor who controls the LSP should analyse and manage all of the design-production elements requested from brother companies to reduce unexpected risks.

LITERATURE REVIEW

Project complexity

The emergence of complexity brings new questions to the construction project in the age of chaos and interdependence. Studies associated with complexity, chaos and uncertainty are steadily increasing in project management research literature (Austin *et al.*, 2002).

Thomas and Mengel (2008) defined complexity from the systematic perspective. They insisted that complex systems are made up of large numbers of multiple-interacting components in which it is difficult to understand the behaviour of the individual components or predict the overall behaviour of the system. In accordance with the study by Vidal and Marle (2008), a synthetic approach can be taken into account for management of complex projects in which different participants will have different perspectives. They assert that synthetic integration of individual characteristics is useful in understanding how the complex personalities can be perceived as a part of project. Migliaccio *et al.* (2008) also investigated implementation of complex projects. They consider design aspects to address rapidly changing construction elements. From the investigation, barriers and facilitations to understand the comprehensive interconnection between individual design and construction elements were presented. They developed a framework to cope with design-related construction elements caused by multinational participants and off-site materials.

Complexity is a feature of a project which makes it difficult to understand, foresee and keep under control its overall behaviour, even when given the complete design information (Owens *et al.*, 2011). Thus, appropriate management of design information is essential for reducing uncertainty risk at early project phase.

Contractor's design management

In design management literature, the research of contractor-led design management started with the shift of procurement from the 1990s. Gray *et al.* (1994) describe the growing importance of contractor's design management (Gray and Hughes, 2001). Contractor's design management was the coordination and regulation of the building design process, resulting in the delivery of a high-quality building. Design management texts have not emphasized sufficiently how contractors can manage the design information and process for the production stage and the challenges they face.

However, different research is being carried out on contractor's design management more recently. Emmitt (2007) found that due to the complexity of current building projects, management responsibility of the contractor has risen even in design aspects. He argued that the contractor should be involved more substantially in the management of design information. Broadbent and Laughlin (2003) emphasised the importance of systematic design management. From the contractors' point of view, design management is a function that coordinates the design information to deliver high-quality performance, enabling the needs of the design, manufacturing, and construction processes to be met. There are more substantial studies dealing with the

contractor's role in design process. Walker and Walker (2012) also studied contractor's early involvement on project; they suggested that because contractors have practical experience of design-related problems on site, they should be involved from the initial project phase as soon as possible.

The role of design management is becoming more systematic and contractor-oriented. Like above studies, involvement of contractor-led design management from initial stages is expanded by improved schedule, cost, safety, and quality performance (Emmitt, 2010).

RESEARCH METHOD

This research focuses on the understanding of the current problems and practical ideas from the collected and analysed data. This research is structured into three parts: the factor identification, data collection, and data analysis. 40 potential DMFs were obtained from diverse academic literature and industrial data. After semi-structured interviews by 11 experts in the construction industry, 21 DMFs were determined to constitute the survey questionnaire. Interviewees were asked to evaluate the appropriateness of selected factors and to add any additional DMFs. The questionnaire was divided into two parts. Part 1 acquired personal and general information. Part 2 evaluated the degree of importance of each factor and the interrelationships between factors. Questionnaires were issued to Korean construction professionals engaged in international-based LSPs as a project manager, site manager, project engineer, or design manager. All respondents were selected from Grade 1 contracting and engineering firms registered with the International Contractors Association of Korea, or the Korea Construction Engineers Association.

284 questionnaires were distributed and 98 valid responses were returned representing a response rate of 34% which is an acceptable response rate for a questionnaire survey. Among the 98 sample, 24 respondents (24.5%) were construction managers, 32 (32.6%) were site managers, 31 (31.6%) were project engineers and 11 (11.3%) were design managers. The majority of the respondents (78%) had over 5 years working experience in their organizations. They were all at middle or higher management levels, which indicate that a high level of accuracy and credibility of the collected data were achieved.

Statistical methods were used for the analysis. The analytic hierarchy process (AHP) was used for data analysis. AHP analysis uses a hierarchy to resolve a decision problem, and then develops priorities for the alternatives throughout the system (Saaty, 1987). Each survey question was designed for pair-wise comparison, thus interrelationships between two target factors can be evaluated and analysed more substantially. Through the pairwise comparison, a more accurate relationship between two target factors can be achieved than result from statistical group response (Whang and Kim, 2014). The respondents selected one DMF which was deemed more critical between the two target factors by people with actual project experiences or professional knowledge. By the above procedure, the importance of each DMF was evaluated, and also the degree of the relationship between two compared factors was presented. Based on the results, all factor interrelationships were shown alongside how strong the relationships are between the factors and which factors have multi-relationships with other critical DMFs.

The importance and priority weight of each factor are ranked and shown in Table 1 with Figure 1 showing the different interrelationships among factors. Based on factor

interrelationships in Figure 1, synthetic causal loop diagram was established as seen Figure 2.

DATA ANALYSIS AND DISCUSSION

Importance weight evaluation

Important weights of all DMFs are evaluated by AHP analysis. The first step of AHP analysis is to classify a hierarchy by organizing the critical DMFs. The next stage evaluates the relative importance of each factor using a set of pair-wise comparison matrices by a nine-point scale using a scale from 0_(lowest level) to 9_(highest level) (Al-Harbi, 2001). The survey respondents selected one factor that seemed to be more important corresponding to the factors being compared. According to the respondent's determination on a chosen factor, importance weight of each DMF was estimated. AHP also measures the overall consistency of judgments by means of a consistency ratio (CR). The CR provides a way of measuring how many errors are created when providing the professional judgment (Saaty, 1987). If the CR is below '0.1', the errors are fairly small and thus, the final estimate can be accepted. If it is more than '0.1', the judgments may be somewhat random and should perhaps be revised. After CR checking, if the figures present inconsistent results, judgment should be repeated.

The priority of the DMFs was also presented as a concrete figure according to each weighted result as seen in Table 1. Unlike importance weight, factor priority allowing multiple responses means favourable and acceptable factor by construction experts. In other words, even if high priority factors cannot be perceived as very important, they are recognized as indispensable in design management. Thus, these DMFs would be considered and applied into the real LSPs.

Through the AHP analysis, all DMFs have both importance and priority weight. Among 21 factors, management of the design interface between international design firms (F17), standardization of different types of drawings (F7), proposal of value engineering (F3), and integrated design management teams on-site (F5) are ranked as the top four critical factors. In comparison to other factors, they have significantly high importance weights (at least over 9%). The sum of these four factor weights is more than 40% of the total weight. Because these four factors can influence the whole project duration and performance, they can be incorporated into the project design management process at the initial project stage.

Oppositely, low ranked factors have specific and regional features. For example, some factors focus on multinational aspects such as building code interface management between different global standards (F16) and regular detailed design meetings with subcontractors and suppliers (F12). The other factors including changed data management during production stage (F20) and prior discussion on major buyer's requirements (F18) are directly related with Korean features. The sum of the importance weight of the 5 lowest factors (11.372) is less than weight of the highest factor. However, because these factors are interconnected with diverse factors as seen in Figure 1, from the systematic perspective, they can influence high ranked critical factors.

Table 1: Importance weight and priority result

No	Design management process factor	Rank	Importance Weight (%)	Priority Result (%)
F17	Management of design interface between international design firms	1	11.678	6.128
F07	Standardization of different types of drawings	2	10.231	6.016
F03	Proposal of value engineering	3	9.267	4.425
F05	Integrated design management team on-site	4	9.086	8.112
F01	Project documents review	5	6.138	9.015
F06	Application of BIM	6	5.232	7.261
F02	Review of the design level compared to budget	7	4.592	3.623
F15	Changing design coordination	8	4.461	5.063
F04	Application of project management information system	9	4.188	3.727
F09	Documents management according to Fast-Track	10	3.872	5.152
F10	Structural grid planning review(over design, omission)	11	3.731	3.521
F14	Off-site construction manual and guideline	12	3.627	3.368
F19	Interior finishing simulation	13	3.468	3.362
F08	Establishment of design integrity checklist	14	3.374	3.492
F21	Support for an environmental building certification	15	3.142	3.427
F11	Making criteria for pre-assembly process on site	16	2.541	3.127
F13	Approval working drawing and sample material	17	2.497	6.113
F16	Building code interface management between different global standards	18	2.484	4.540
F20	Changed data management during production stage	19	2.303	3.051
F18	Prior discussion on major buyer's requirements	20	2.059	3.214
F12	Regular detailed design meetings with subcontractors and suppliers	21	2.029	4.263

* Priority results include multiple responses

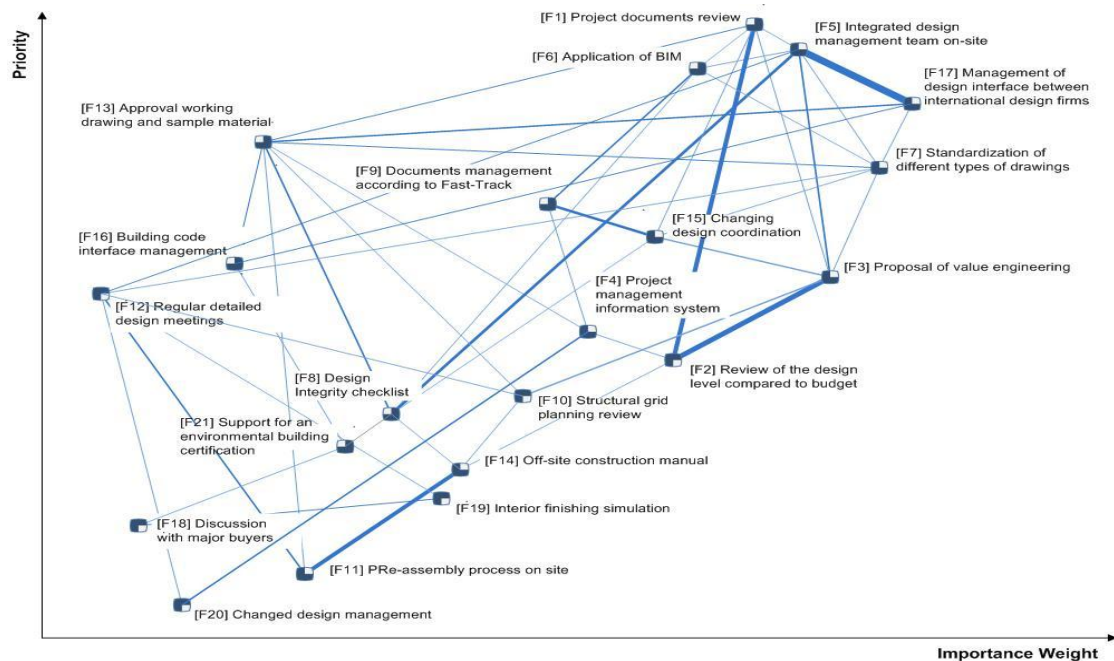
Factor interrelationship evaluation

Factor interrelationships are meaningful as much as the importance weight. All DMFs can have advantageous or disadvantageous impacts on project performance simultaneously. In addition, some factors which are quite advantageous in the early stages can have serious influence on the project performance later on. For example, Application of BIM (F6) factor can be advantageous to improve productivity. However, at the same time it also can cause the increase of construction cost and duration due to out-sourcing costs for BIM modelling and training cost for BIM operators.

In Figure 1, all DMFs are located on the graph based on priority and importance weight. Herein, factors which have strong and closed relationship with other factors are expressed as bold and thick lines according to the questionnaire response. Overall, high priority factors have diverse relationships with other factors, while high importance weight factors have more strong relationships comparatively. Figure 1 indicates that high ranked factors in both importance weight and priority such as F1

and F5 have various and strong relationships with other factors at the same time. Indeed, these kinds of factors can have a dominant influence on whole project performance, particularly in small and middle size projects. However, in international-based LSPs, the efficient integration of diverse factors is more critical than focussing on a small number of predominant factors. Thus, even if some factors do not have high importance weight such as F12 and F13, they can play as a hub factor having diverse interrelationships with other DMFs; indeed F12 and F13 have 8 and 6 relationships with other factors respectively.

Figure 1: Interrelationship between design management factors



CAUSAL LOOP DIAGRAMS

The traditional management approach assumes that if each project component can be understood, then the whole project can be controlled easily. However, the interrelationship between components of LSPs is more complex than the linear thinking system from the traditional approach. Thus, comprehensive approaches such as the causal loop diagrams which focus on system structure have received attention (Wolstenholme, 1990). Causal loop diagram is an analysis method for system dynamics used for the development of complex, long-term, or one-off projects such as spaceships, computer programs, or offshore plants. International LSPs have similar features of complexity with above projects; hence causal loop diagrams have been used for different LSPs to analyse structural features or project systems. Even if it cannot provide the detailed schedule and cost solution, it can improve the understanding of the project system and provide evaluation of major parameters from the structural perspective.

Figure 2: Design management factor causal loop

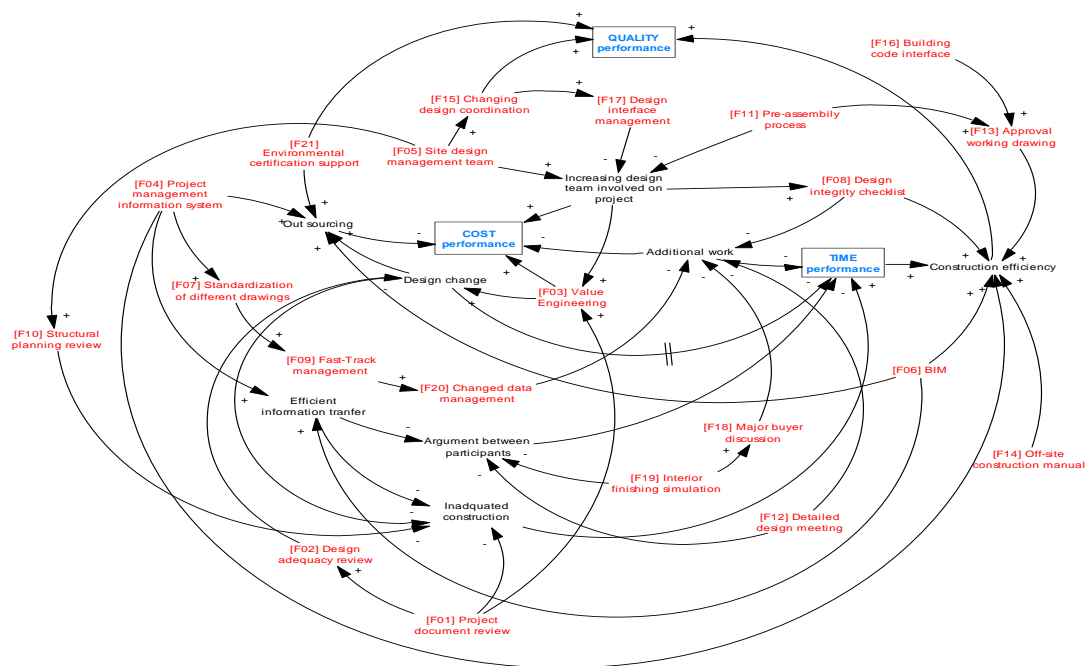


Figure 2 shows the causal loop diagram as a DMD for a LSP, which considers the interrelationship between DMFs. The diagram reflects the cost, time, and quality performance during the production stage. Among DMFs, only two factors (F03, F15) influence project performance directly; F03 and F15 impact on cost and quality performance, respectively. Others mutually influence each other or impact on other dependent elements. By the establishment of a causal loop diagram at early pre-production stage, contractors can establish their design management strategies and substantial implementation plans according to the project performance target. For example, if contractors should reduce the construction costs at a certain production stage, preferentially they can consider the value engineering proposal (F03). This factor is ranked 3rd on importance weight (see Table 1); it also has a direct relationship with cost performance (see Figure 2). However, if there is no specific performance target, contractors may consider the integrated design management team on-site (F05). Even if F05 cannot influence on in any performance target directly, it give impact on quality and cost performance as well as other DMFs at the same time.

CONCLUSION

Contractors are facing increasing risk and uncertainty on projects caused by complexity. In the Korean construction industry contractors are more responsible for the whole project from design to production; this is of particular importance where international design teams are involved with indigenous local design partners. To manage uncertainty caused by such design-production risk, this research focused on the establishment of the contractor-led DMD from pre-production stage. Through data analysis, collected DMFs were ranked by importance weight and expressed by factor interrelationships. The data was used to establish causal loop diagrams in order to understand the structural features of whole project. Viewing a causal loop diagram can help to provide a comprehensive insight into the fundamental dynamics of the project elements. With this insight, contractors can recognize which DMFs should be considered and implemented as a DMD according to project performance targets and conditions. Such information is very valuable, helping contractors to prepare

appropriate construction methods and to organize resource allocation at pre-production stage. The causal loop diagrams can also be used in system dynamics simulation. Through the simulation, optimal and balanced design management strategy can be established from the contractor's perspective to minimize project uncertainty.

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CONCEPTUAL FRAMEWORK FOR RISK PROPENSITY, RISK PERCEPTION, AND RISK BEHAVIOUR OF CONSTRUCTION PROJECT MANAGERS

Wenqian Wang¹, Junqi Zhao, Wenjing Zhang and Yu Wang

College of Management and Economics, Tianjin University, Tianjin, China

Although a number of quantitative risk management measures and methods have been developed, the risk decision-making behaviour of construction project managers still needs to be further considered. Taking the characteristics of construction projects into consideration, this research put forward an integrated framework from the perspective of construction project managers and proposes 11 general hypotheses, putting risk propensity and risk perception in central roles. Individual differences, including demographic traits, personality differences, and knowledge and experience are identified as factors affecting risk propensity of construction project managers. Risk perception, on the other hand, is mainly influenced by magnitude or probability of potential gain or loss, problem framing, and culture influence. Questionnaires were distributed and multiple hierarchy regressions were employed to test 2 of the 11 hypotheses. The results confirm that extraversion positively influences risk propensity while agreeableness negatively does. Besides, risk propensity has a negative influence on risk perception of construction project managers. Propositions derived not only shed light on guidance for future research on the risk behaviour of construction project managers, but also provide decision-making support through a better understanding of the factors affecting risk behaviour. More empirical tests of the proposed hypotheses should be conducted in future researches.

Keywords: construction project manager, risk decision-making, risk perception, risk propensity.

INTRODUCTION

A construction project is plagued with various risks and uncertainty due to its complex and dynamic nature. Risk management as well as the quality of risk decisions thus plays a critical role during the implementation of construction projects. As an overall planner, controller, and coordinator of a project, the construction project manager must ensure the requirements of completion on time, within budget and required quality standards (Rwelamila, 1994). A project manager is the main decision maker of the project, taking the major responsibility of the risk assessment and management. Risk decision-making behaviour of the project manager thus is critical to the project success. A better understanding of risk behaviour of decision-makers can contribute to risk management programs in project organizations.

Previous research has developed various methods to study the risk decision-making, including expected profit and loss value decision method, the Bayesian decision

¹ wangwenqian82@163.com

method, the Markov decision method, etc (Wang and Yuan, 2011). However, quantitative studies about risk decision-making (e.g. mathematical programming, economic models) have both practical and theoretical limitations (Lin and Chen, 2004) for they rarely focused on the characteristics or behaviours of decision-makers. It is stated that decision-makers perceive risk differently when faced with various situations, the reasons of which refer to early experience, education background, personal beliefs, and culture (Alexopoulos *et al.*, 2009). Therefore, when it comes to risk behaviour of decision-makers, the subjective factors influencing the way project managers make decision cannot be ignored. Risk decisions during the implementation of construction projects are not only based on the rational evaluations of the likelihood and magnitude of risks, but also rely on the personal traits of the project manager.

A mediated model of the determinants of risk decision-making was proposed by Sitkin and Pablo, indicating that risk propensity and risk perception of the decision-maker are the main variables influencing risk decision-making behaviour (Sitkin and Pablo, 1992; Sitkin and Weingart, 1995). Meanwhile, organizational (Thomas *et al.*, 1993), personal and project characteristics (Müller *et al.*, 2009) are contextual factors which may produce impacts on manager's decision-making. Most of the research on risk propensity, risk perception, or risk behaviour is based on the theory of behavioural decision, generally from the domain of psychology. Little attention was given to factors influencing decision-makers' risk propensity or risk behaviours in construction projects (Wang and Yuan, 2011). Thus, this research tends to find out the critical factors affecting project managers' risk decision-making behaviours. Based on the literature and hypotheses, the purpose of this research is to build up a conceptual model about the relationship among various antecedents, risk propensity, and risk perception of project manager, which also takes the effects of project attributes into considerations.

THEORETICAL BACKGROUND

Risk Propensity

Risk propensity, also conceptualized as an individual's risk-taking tendency, is defined as an individual's current tendency to take or avoid risks and considered as an individual trait which can change over time as a result of experience (Sitkin and Pablo, 1992; Sitkin and Weingart, 1995). An individual's willingness to take or avoid risks may have a significant impact on his decision-making under conditions of risk and uncertainty (Keil *et al.*, 2000). Important decisions take place under conditions of incomplete information, thus it is impossible for project managers to gather all the information and take all risks into consideration to make the wise decisions. In such situations, the decision-makers' risk propensity may play an important role.

Risk propensity is considered to be a situational-specific variable, indicating that a decision-maker's risk propensity differs in various situations (Keil *et al.*, 2000). There is plenty of research on risk propensity of executives (Brockhaus, 1980; MacCrimmon and Wehrung, 1990; Wiseman and Gomez-Mejia, 1998). However, there is limited research conducted in the construction domain, except for a few studies, such as Han *et al* (2005) studied the risk attitude of contractors when making bid/no bid decision of international projects. Wang and Yuan (2011) also identified the critical factors affecting contractors' risk attitudes in construction projects. This research aims to study the risk propensity from the perspective of project managers in the construction context.

Risk Perception

Risk perception refers to “a decision maker’s assessment of the risk inherent in a situation” (Sitkin and Pablo, 1992). As an inherent part of the decision-making process, risk perception could be understood as an individual’s assessment of risk. It means that when individuals are faced with identical situations, some consider the situation to be very risky, while others believe it is with low risks. There is a high chance that decision-makers who perceive low level of risk might take risky actions even if they are risk averse. Forlani and Mullins (2000) put forward a framework which indicates risk perception of entrepreneurs, venture characteristics, various contextual effects, and individual traits play key roles in entrepreneurs’ decisions to enter new ventures.

Risk perceptions of various individuals may differ due to certain types of cognitive biases lead people to perceive different levels of risk (Simon, Houghton, and Aquino, 2000). According to Simon *et al.* (2000), cognitive biases can directly influence risk perception, which further produces impacts on the decision of individuals to start a venture. There are a certain number cognitive biases types, for instance, overconfidence, covariation and control, availability, representativeness, multi-stage evaluation, and so on (Simon *et al.*, 2000).

HYPOTHESES AND CONCEPTUAL MODEL

Sitkin and Pablo (1992) put forward a reformulated model integrating the determinants of risk behaviour and argued the mediating mechanisms of risk propensity and risk perception. Thus, individual characteristics, such as risk preferences, inertia, and history of prior outcomes of risk decision-making, affects risk behaviour indirectly through the impact on the decision-makers’ risk propensity. On the other hand, organizational and problem characteristics, including cultural risk values, organizational control systems, problem familiarity, problem framing (Kahneman and Tversky, 1979), affect risk behaviour only by influencing what is perceived (risk perception). Based on the three aspects, namely individual, problem-related, and organizational characteristics, the following sections aim to find out the effects of key variables on the project managers’ risk propensity and risk perception in construction projects.

Hypothesis 1: Higher levels of risk propensity of construction project managers lead to riskier risk decision-making behaviour.

Hypothesis 2: Construction project managers’ risk behaviour is negatively associated with their levels of risk perception.

Factors Influencing Risk Propensity

Demographic traits

Upper echelons theory put forward that the executives’ personalities greatly influence their interpretations of the situations they face and, in turn, affect their choices or decisions (Hambrick, 2007; Hambrick and Mason, 1984). The demographic characteristics of executives can be used as valid, albeit incomplete and imprecise, proxies of executives’ cognitive frames (Hambrick, 2007). The demographic traits of project managers are thus associated to their way of making risk decisions.

As for age, young males or females take more risks than older males or females, based on which it is proposed and then verified that risk propensity will be inversely related to age (Nicholson *et al.*, 2005). As for gender, women are found to be more risk

averse than men when facing gambling situations. It is also assumed that female project managers are less risk taking.

Lots of studies have been conducted to explore the magnitude of relative risk aversion or risk taking, but there is little consensus and few generalizations to be concluded from the existing literature (Halek and Eisenhauer, 2001). Therefore, this research tries to explore the relationship between demographic traits and risk propensity of project managers in the construction context.

Hypothesis 3: Risk propensity of construction project managers is negatively related to age. Meanwhile, female project managers tend to be more risk averse compared to male managers.

Personality

Personality traits are predictable characteristics of individual behaviour which can explain differences in actions of people in similar situations (Koe Hwee Nga and Shamuganathan, 2010). This research mainly uses the conception of the Big Five model, namely extraversion, agreeableness, conscientiousness, emotional stability, and openness to experience.

Extraversion trait is manifested by sociable, outgoing, positive attitude and assertive characteristics (Ciavarella *et al.*, 2004), which creates a positive drive to risk-taking propensity and need for achievement. Agreeableness trait concerns the ability to foster social consensus in order to maintain mutual trust (Llewellyn and Wilson, 2003). Overly agreeable personality may result in compromising to gain acceptance and lower risk-taking propensity (Koe and Shamuganathan, 2010). Conscientiousness is related to an individual's meticulousness, responsibility, industriousness, which may promote their dependability at work (Ciavarella *et al.*, 2004). Emotional stability represents individual differences in adjustment. Individuals who are more emotional stable can be characterized as self-confident, clam, and relaxed (H. Zhao and Seibert, 2006). Openness to experience is a personality dimension which indicates that individuals tend to seek new experience and explore novel ideas (H. Zhao and Seibert, 2006). Individuals who are high on the dimension of openness tend to be versatile, imaginative, and often face challenges and display creativity (Llewellyn and Wilson, 2003). It thus can be regarded as a cognitive stimulus for risk seeking, chartered as acceptance of experimentation, tolerance of the uncertainty, change and innovation.

Much research has examined the relationship among personality trait, risk propensity, and entrepreneurial status (Miner and Raju, 2004; Nicholson *et al.*, 2005). The relationship between risk propensity and big-five model personality is however controversial (H. Zhao and Seibert, 2006). Limited research has been conducted to explore the relationship between personality and project managers' risk propensity. Thus it is necessary to test the relationship in the construction industry.

Hypothesis 4: Extraversion and openness to experience are positively related to project managers' risk propensity, while agreeableness, conscientiousness, and emotional stability are inversely associated with risk propensity.

Knowledge and experience

Knowledge mainly refers to professional knowledge of project managers. Professional knowledge, and scope of knowledge all play significant roles in influencing contractors' risk attitudes in the Chinese construction industry (Wang and Yuan, 2011). Thus, it is also considered to be important for the project manager, as the main individual who is responsible for the whole construction project, to have a good

knowledge of all work in projects. Project managers with adequate knowledge are likely to be more confident in his decision-making, thus becoming more risk taking.

Hypothesis 5: The risk propensity of construction project managers is consistent with their professional knowledge.

Experience section mainly considers project managers' engineering experience and social experience. It is noted that people tend to fear risk involved in an activity which they are not familiar with. As an individual's experience of problems or tasks increase, he is willing to accept higher levels of risk (Richards *et al.*, 1996). In the construction context, before a person becomes a project manager, there is high probability that he has gained 5-10 years of experience working in the construction sites. Adequate engineering and social experience are thus the foundation of project managers' decision-making and make them feel confident in the construction field.

Hypothesis 6: As construction project managers obtain more and more engineering and social experience over time, this will influence their risk propensity.

Factors Influencing Risk Perception

Risk propensity and risk preference

Risk propensity may influence the relative salience of threat or opportunity under certain situations and thus cause biased risk perception (Brockhaus, 1980; Sitkin and Weingart, 1995). A risk-averse decision maker tends to weight negative outcomes more heavily than positive outcomes and overestimate the probability of loss, leading to a heightened perception of risk. Conversely, a risk-seeking decision maker is likely to weight positive opportunities more heavily and overestimate the probability of gain. Scholars also confirmed risk attitude as a prominent explanatory role in shaping risk perception (Sjöberg, 2000).

Hypothesis 7: The higher a construction project manager's risk propensity, the lower the level of perceived situational risk.

Magnitude or probability of potential gain or loss

Risk is conceptualized as a function of probability (likelihood) and magnitude or regarded as the combination of the probability of desirable events and the magnitude of loss associated with such events (McNamara and Bromiley, 1999). People's risk perception is based more on risk magnitude than on probability, meaning that the magnitude of potential loss is a more influential factor in shaping risk perception (Keil *et al.*, 2000). A popular managerial perspective of risk taking behaviour argued that managers consider risk not as a probability distribution but as the size of potential loss from certain decision (March and Shapira, 1987).

Hypothesis 8: The magnitude and probability of potential gain or loss both influence the construction project managers' risk perception and within different situations the role of magnitude and probability may change.

Problem framing

Problem framing, which refers to whether a problem is framed in positive or negative terms (Sitkin and Weingart, 1995). Prospect theory stated the opinion that positively framed situations resulted in risk averse decisions (Kahneman and Tversky, 1979). However, it should be noted that research also showed positively framed problems foster risk taking because they can draw more attention to the opportunities (March and Shapira, 1987). Emphasizes on the potential losses would heighten the salience of risk, while stressing the potential gains is related to a lower level of perceived risk.

Thus, there exist differences about the relationship of problem framing and risk perception. New research should be considered in the context of construction.

Hypothesis 9: Construction project managers in positively framed situations will perceive lower risk than negatively framed situations.

Culture influence

Researchers have argued that cultural theory is an important explanatory scheme for understanding risk perception (Sjöberg, 2000). Cultural norms and values play an indispensable role in shaping people’s risk perception (Alexopoulos *et al.*, 2009).

Hofstede's (1980) way of cultural division is accepted. Uncertainty avoidance is often related to high levels of aversion to risk. Americans and northern Europeans are highly convinced that they can control events, while East Asian cultural groups tend to hold the view that events are complex, which are affected by various factors and are inevitably less controllable (Nisbett and Masuda, 2003).

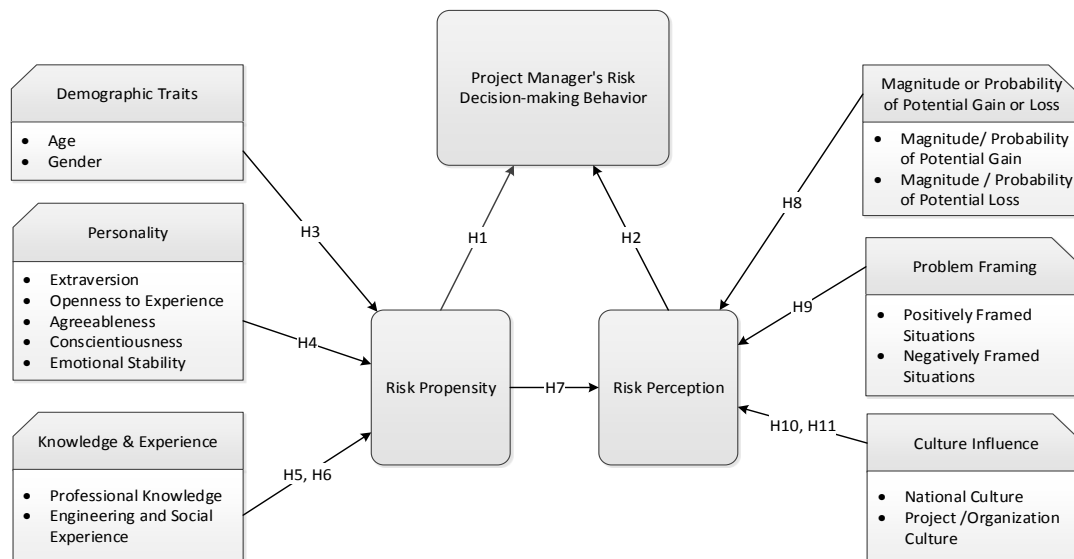
Cultural risk value is defined as organizational tendency to prefer certainty versus uncertainty and risk avoiding versus risk taking (Douglas and Wildavsky, 1983). Thus, the cultural risk value of a project, which indicates or reflects broader attitudes toward uncertainty and risk, may provide important guidelines for project managers when they make risk decisions. Specifically speaking, being in the risk-seeking culture, the project manager is likely to be influenced by the project culture and make risk-seeking decisions, even though he might tends to be risk averse naturally.

Hypothesis 10: National culture in different countries is likely to influence the way people perceive risk.

Hypothesis 11: Project culture or organization culture affect construction project managers’ risk perception. To be specific, project managers in construction projects or organizations with higher risk-seeking cultural values tend to take more risks.

Based on the existing theory and empirical findings of previous research, this research proposes a conceptual model of the relationship among individual differences of the project manager, project or organizational attributes, culture influence, risk propensity, risk perception, and risk decision-making behaviour. Figure 1 shows the integrating framework of this research with 11 hypotheses in total.

Figure 1: Conceptual model related to project managers’ risk behaviour



HYPOTHESES TESTS

To partly verify the validity of the proposed conceptual model, this research chose part of the hypotheses to conduct an empirical test. H4 and H7 will be tested, and questionnaires were distributed to gather data in this research.

Sample

All the formal respondents were project managers from Chinese construction industry, whose privacy were highly protected. 150 questionnaires were sent by e-mail to the construction project managers, and 114 replies were received, making the response rate 76%. After the completeness analysis, 48 effective questionnaires were finally employed, making the effective rate 42.1%. The sample size is not that large because it might be more difficult to gather data from construction project managers only, as the number of project managers is markedly less than general employees.

Measures

The Big Five personalities

Gosling *et al.* (2003) developed a simple Ten Item Personality Inventory (TIPI) based on previous complex scales, and tested the reliability and validity of TIPI. Scholars have translated TIPI into Chinese, and the reliability and structural validity are all acceptable. This research uses TIPI to measure project managers' personalities.

Risk propensity

The scale measuring risk propensity in this research is a 5-item scale called General Risk Propensity (GRP), employed from Hung and Tangpong (2010). This scale has also been modified and tested under Chinese context.

Risk perception

Psychological measures are usually used to measure risk perception in construction area. Respondents are asked to evaluate the probabilities for certainty risk factors. In this research, 29 risk factors were used based on the research of Zou *et al.* (2007).

Control variables

Four variables are considered as control variables, namely gender, age, working experience and education background. These individual traits might be correlated with independent variable, and would have influence on risk propensity. So they should be controlled to get the real influence of personalities on risk propensity.

Results and Analysis

The Cronbach's alpha for extraversion, agreeableness, conscientiousness, emotional stability, openness to experience and risk propensity was 0.748, 0.672, 0.663, 0.651, 0.763 and 0.824 respectively, indicating the internal consistency of the scales was acceptable. Then a confirmative factor analysis was conducted to test the structural validity of Big Five Personality Model. Results show satisfactory support for it (CMIN/DF=2.001, CFI=0.909, NNFI=0.837, GFI=0.912, RMSEA=0.100).

Multiple hierarchical regressions were applied to test the developed hypotheses. The results are shown in Table 1. The results indicate that extraversion is significantly positively related to risk propensity ($\beta=0.128$, $p<0.05$), and agreeableness is significantly negatively related to risk propensity ($\beta=-0.242$, $p<0.01$). In addition, the relationships proposed in H4 between risk propensity and openness to experience, conscientiousness, and emotional stability are not significant. This might be due to not considering different contexts. Research has implied that openness to experience and

emotional stability may positively influence risk propensity if the project gained revenue, while not to influence under loss. These results indicate that H4 is partially supported. When testing H7, the results show that risk propensity is significantly related with risk perception ($\beta=-0.252$, $p<0.001$), suggesting that H7 is supported.

Table 1: Conceptual model related to project managers' risk behaviour

Independent Variable	Risk Propensity		Risk Perception	
	Model 1	Model 2	Model 3	Model 4
Gender	-0.411*	-0.341	-0.027	-0.131
Age	-0.031	-0.025	0.005	-0.002
Educational Background	0.187	0.142	0.033	0.080
Working Experience	0.034	0.016	-0.002	0.006
Extraversion		0.128*		
Agreeableness		-0.242**		
Conscientiousness		-0.034		
Emotional Stability		0.006		
Openness to Experience		0.068		
Risk Propensity				-0.252***
R2	0.084	0.270	0.004	0.138
F	2.216	3.775***	0.100	3.083*

Notes: * $p<0.05$, ** $p<0.01$; *** $p<0.001$

CONCLUSIONS

This research mainly puts forward a conceptual model related to key factors influencing project managers' risk decision-making behaviour in the construction field and set forth a theoretical framework for examining risk behaviour. Three classes of factors influencing risk behaviour are considered, namely individual characteristics, organizational characteristics, and problem-related characteristics. 11 relative hypotheses are put forward through identifying critical factors from literature review. Individual differences, such as demographic traits, personality differences, and knowledge and experience are identified as factors affecting risk propensity of project managers. Risk perception, on the other hand, is mainly influenced by magnitude or probability of potential gain or loss, problem framing, and culture influence. 2 of the 11 hypotheses are empirically tested. The results confirm that extraversion positively influences risk propensity while agreeableness negatively does, and risk propensity has a negative influence on risk perception of construction project managers.

This research yields some new insights into project managers' risk behaviour by integrating perspectives from both risk decision-making literature and risk management theory in the construction context. Prior research often focused on the objective factors of risk and a number of quantitative measures and methods have been developed. However, apart from the objective factors, the individual characteristic of project managers also influence the way they make risk decisions. Studying the relationship between risk characteristics and risk propensity, risk

perception can help improve predictive models about risk behaviour. On the other hand, this research provides project managers a framework for thinking about their own risk propensity and risk perception and how the risk decisions are made. Top managers from the construction enterprises can take the individual differences into account when selecting appropriate project managers.

In addition, this framework is only a starting point to focus on the risk decision-making of project managers. Models or framework are in fact incomplete depictions of the empirical world. Additional work and research should provide more potential influencing factors, revisions, or even challenges to this conceptual model. As to the methods of the research in the future, qualitative method of interviewing is considered as an appropriate way to collect data. Researchers can interview the project managers to discover how they interpret situations, what are their concerns when facing particular issues or problems, how they make final decisions, etc.

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TRAINING PROVISIONS FOR RISK MANAGEMENT IN SMES IN THE UK CONSTRUCTION INDUSTRY

Ali Rostami¹, Atousa Khodadadyan, James Sommerville and IngLiang Wong

School of Engineering and Built Environment, Glasgow Caledonian University, Glasgow G4 0BA, Scotland, UK

Risk management continues to be well recognised as an integrated key function of the enterprises management process in the construction industry. Literature has established that it is rapidly becoming an indispensable approach adopted by organisations in the industry for achieving strategic business objectives. However, due to inadequate provision of training programmes in risk management, Small and Medium Enterprises (SMEs) mainly suffer from its lack of implementation. Focus of training on the general concept of risk management without considering the organisations' characteristics and requirements has influenced the SMEs' understanding of risk management. On the basis of a semi-structured interview and qualitative research with SMEs, the nature of training provisions of risk management in SMEs in the UK construction industry was discussed. 30 participants outlined that training within organisations, particularly in SMEs, is a complex and context-embedded activity. Its development requires a full consideration of organisational characteristics including the system of management; level of resources; degree of employees' knowledge; and objectives of the organisation. The result of the study also indicated that risk management training programmes have to be geared to the organisational activities to deliver the benefits and advantages of the process. It needs to provide a proven method for incorporating risk management processes as integral elements of business management. Moreover, training should focus more on creating the learning environment that supports employees to improve efficiency by controlling the risks of activities.

Keywords: risk management, training provision, small and medium enterprises.

INTRODUCTION

Over the past few years, significant changes in the UK construction industry - i.e. practice of Building Information Modelling (BIM) process - have imposed considerable pressure on its organisations to respond adequately to their business environment (Holt *et al.*, 2000). Requests for industry improvement resulted in the emergence of numerous government commissioned reports evaluating the industry's structure, culture and operation (Latham, 1994 and Egan, 1998). The critical role of Risk Management (RM) for improving the organisational operation within the construction industry has been confirmed by those reports. RM was introduced as a process to promote productivity and business entrepreneurship by managing uncertainties (Chapman and Ward, 2008). This view is supported by the UK Government through the British Standard focusing on RM (BS 31000:2009). It is argued that the main drivers behind the practice of RM among enterprises operating in the UK construction industry are the prerequisites from the government for industry

¹ ali.rostami@gcu.ac.uk

improvement and the individuals' demands to obtain competitive advantage in their organisation.

Recent studies in the UK construction industry indicated the weak reputation of RM within organisations (Lyons and Skitmore, 2004; and Smith *et al.*, 2014). The researches by Bowen (1993) and Liu and Cheung (1994) explained that the challenge in the implementation of RM within organisations is mainly related to professionals' inadequate level of knowledge in RM concepts and mechanisms. Couillard (1995) highlighted that, even management with frequent use of RM find it difficult to understand the rationale for and formal process of RM in new projects. Diversity in parties' perceptions in a construction project invites undesirable biases in decision making which makes the process of managing risk more complicated and unacceptable (Liu and Cheung, 1994). Researchers such as Akintoye and MacLeod (1997), and Carr and Tah (2001) indicated that a small number of organisations practise formal RM systems with analytical approaches in assessing risks. They identified the "*human problem*" which is associated with knowledge and experience of the key players as an initial barrier for RM implementation in the construction industry. Rostami *et al.*, (2015) through an empirical research outlined the role of risk management training programmes in the mitigation of the human problem. They specified that an appropriate training programme assists SMEs to raise awareness of risk management concepts and mechanisms, and enables them to adapt RM based on organisational characteristics.

This paper evaluates the nature of training provisions for RM in SMEs in the UK construction industry through semi-structured interviews which were fundamentally designed and developed based on a broad review of literature on SMEs' characteristics and the key issues in RM.

TRAINING FOR RISK MANAGEMENT IN SMES

The degree of receiving benefits from RM is dependent on the professionals' quantitative backgrounds and their ability to interpret and apply RM concepts within organisations (Wood and Ellis, 2003). Education and training as two essential factors play a significant role in the development of professionals' ability within organisations. Professionals in construction organisations use both education and training to bridge the gap between theory and practice in RM (Akintoye and MacLeod, 1997).

The objective of education and training is to improve performance by developing skills and knowledge (Lane, 1987). Education in this context conveys the general knowledge and understanding of the environment which improves the employees' observation, analysis and decision-making abilities. However, training is concerned with employees' performance in a specific area or job which they are hired to do (Flippo, 1961). Goldstein (1980) explained training as the "*acquisition of skills, concepts, and attitudes that result in improved performance in all job environments*".

The theory and processes of risk management have been extensively explained by professional bodies and in standards; however, none of these have addressed the fundamental principles of applying the process to the situation that small and medium-sized enterprises find themselves in (APM, 2010). Evidence indicates that training programmes to support risk management implementation and its continued application are inadequate for SMEs. Few training programmes exist in the area of risk management that consider the practitioners' size and capability; and most training

courses address risk management practices in large enterprises with less attention to SMEs' characteristic. (Rostami *et al.*, 2015)

A review of the literature on RM in the construction industry indicated three major barriers to training (Akintoye and MacLeod, 1997; and Chileshe and Kikwasi, 2013). The first barrier is concerned with financial resources for training programmes. The second is the absence of adequate capability to run training programmes. And the third is the limited time people have to attend the training programmes. Many SMEs, due to their characteristics, suffer not only from resources restriction but also from inability to carry out training programmes, despite there being a need for initiating, planning and implementing the training. Wood and Ellis (2003) also highlighted that there is a limited evidence of employees receiving training on formal RM. Thus, there is an empirical requirement on training for RM in SMEs in the construction industry.

RESEARCH METHODOLOGY

This research aimed to determine the nature of training provision for RM in SMEs in the UK construction industry that can be applied to the development of a RM framework for SMEs. As a whole, the study was based on a sequential explanatory mixed method and included quantitative and qualitative studies. This paper embraced the qualitative part of the study with literature review.

The data for the study was obtained by means of semi-structured interviews. Organisations which participated in this study employed more than 10 people but less than 250. Database for the study was obtained from the Office of National Statistics (ONS), the Small Business Gateway, the Financial Analysis Made Easy (FAME) and the Scottish Centre for the Built Environment (SCBE).

The non-probability 'self-selection' sampling technique was adopted to seek assistance from organisations that highlighted their interests in the research topic at the first (quantitative) part of the study. Saunders *et al.* (2009) stated that unlike quota and probability samples, there are no rules for sample size in a non-probability sampling approach; rather, the actual size depends, among other things, on available resources and the logic behind the sample selection. This argument is supported by Patton (1990), who maintains that the validity and understanding that the researcher will gain from the data in this type of sampling will have more to do with the data collection and analysis skills than the size of the sample.

The period of the study was from the 10th of April to the 21st of May 2013. 30 small and medium-sized enterprises participated in this study (Table 1). Attempts were placed to have samples across architecture, engineering, quantity surveyors, and construction organisations.

Table 1: Organisation distribution which participated in the study

Organisation	Architecture	Engineers	Contractors	Quantity Surveyors	Total
Small	3	5	5	4	17
Medium	2	3	4	4	13
Total	5	8	9	8	30

Through the semi-structured interviews, the subject of risk management training was discussed. The first part of the semi-structured interview stimulated responses of participants in risk management training strategy. It considered delivery methods and

different types of training with information about barriers in risk management training within organisations. The second section discussed the nature of the current training provisions for risk management in SMEs. The last section addresses the nature of future training which is required for risk management in SMEs in the UK construction sector.

Content analysis was adopted to convert the obtained large quantities of data from interviews into a meaningful and usable format. Coding and analysis of the interview sessions were accomplished by NVivo 10. The responses were arranged through the Nodes field. Nodes included tree-nodes and sub-nodes which formalised the hierarchy structure of the data. There were sixteen questions in the research interview; thirteen questions were asked in part 1 and three questions in part 2. In total, there were seven sub-nodes under the interview response by questions category.

THE NATURE OF RISK MANAGEMENT TRAINING CURRENTLY IMPLEMENTED BY SMES

The aim of training within enterprises is to enhance the efficiency of employees and consequently businesses (Hughey and Mussnug, 1997). Mathieu *et al.* (1992) outlined that individuals' skills are directly dependent on training which expands their current knowledge and experience. Training in risk management assists organisations in developing personnel's understanding of the process and thereby controlling the business environment. Training is in general categorised into internal and external training courses. Internal trainings are mainly carried out by senior staff with a sufficient degree of knowledge and experience within the organisation; however in external trainings, the employees attend courses provided by professional organisations.

Training for risk management should be developed according to the work environment (Isaac, 1995). They need to demonstrate some benefits from the practise of risk assessment and risk control in projects (Capleton *et al.*, 2009). A literature review outlined that training for risk management had not been fully developed (Akintoye and MacLeod, 1997; Uher and Toakley, 1999; and Lyons and Skitmore, 2004), albeit risk analysis trainings in construction projects had been offered by many professional bodies.

Through the semi-structured interviews, the subject of risk management training was discussed. The first part of the semi-structured interview that stimulated responses of participants in risk management training strategy was, "is there a specific risk management training programme in your organisation?". The analysis of collected data revealed three types of managerial strategies for training (Table 2).

Table 2: Training Strategies within SMEs

Type of training strategy	Small	Medium	Total	Percentage
General training plan	12	14	26	87%
Specific training plan for risk management	8	13	21	70%
No training plan	4	0	4	13%

Twenty-six participants out of 30 enterprises highlighted that there was a general training plan within their business plan. The training programmes were mainly provided by construction professional bodies such as The Royal Institution of Chartered Surveyors (RICS), The Chartered Institute of Building (CIOB), The

Institute of Structural Engineers (ISE), The Royal Institute of British Architects (RIBA), Construction Industry Training Board (CITB) and the National Construction College.

Twenty-one out of 26 organisations had specific plans for risk management training. The enterprises without a risk management training plan stated that risk management training courses in the construction sector were only applicable to large organisations, and to the best of their knowledge, no external training programme had been designed on the basis of small-sized enterprises' characteristics. Also, lack of on-the-job training programmes to meet the organisational objectives was highlighted as the second barrier to the risk management training.

From the data in Table 2, it is evident that 4 of the 30 organisations had no general or specific plan for risk management training within their organisations. All those companies were small-sized enterprises. They mostly named time and budget limitations as the key barriers to training. A sub-contractor's owner-manager stated that planning and running training programmes require a considerable degree of investment in time and budget, as well as significant human resources – hence training disrupts business' activities and wastes organisational assets. Another manager from a small organisation defined training programmes as total waste of time. He argued that the organisations could save resources with less training sessions and by employing experts. The SMEs mainly recruited professionals to utilise their expertise in their construction business, and hence there was no need for training investment.

In this study, twenty-six interviewees out of 30 stated that they preferred to have in-house and on-the-job training for risk management. This outcome confirms the result of the past research of the CITB which outlined that most construction enterprises select in-house training programmes instead of external courses. The study's result indicated that after nearly twenty-seven years the industry's attitude towards the training courses had not changed. Lyons and Skitmore's (2004) empirical study focused on the Queensland engineering construction industry also underscored in-house training as the most popular method of training. They specified that the most beneficial risk management training that organisations had received was through in-house training and experience.

Eighteen of the 21 organisations with specific training plans for risk management indicated that they held in-house training sessions for risk management for their construction projects. They classified those trainings into on-the-job and off-the-job trainings (Table 3).

Table 3: In-house and Public Scheduled Trainings within SMEs in the Construction Sector

Training methods for risk management	In-house		Public scheduled trainings	Total
	On-the-job	Off-the-job		
Small	6	1	1	8
Medium	9	2	2	13
Total	15	3	3	21

Fifteen out of 18 interviewees that practice in-house training, indicated that they implemented and practised on-the-job training for risk management, while three interviewees used off-the-job training for managing risk. They named full concentration on learning rather than performing, and freedom of expression as the

main factors for selecting off-the-job methods. On the other hand, fifteen interviewees pointed out travel cost saving, more focused training, use of current work examples, team building and convenience structure as the key features of on-the-job training.

The Job Instructional Technique (JIT), Apprenticeship and Mentoring were revealed as the most practised methods for on-the-job training within SMEs. These methods provide a practical form of risk control for practitioners. JIT and Mentoring techniques assist managerial trainees to have an overview of the involved risks, their impacts, and the desired results (APM, 2010).

Through JIT, the trainer illustrates the task or the skill to trainee, and allows trainee to demonstrate his/her understanding on the job. This technique delivers a step-by-step learning process, highlighting when the trainee has learned. One of the interviewees stated that this method was a valuable tool for trainees, which also affords practitioners the possibility to receive feedback on each stage in the work-place.

The second revealed apprenticeship as their training method for on-the-job training. Five organisations were practising this method as a mode of risk management training. Chand (2014) defined apprenticeship as a system which trains a new generation of practitioners for a skill. This method is used in particular trades and is mainly facilitated by practical experience (Egbu *et al.*, 2003). One small-sized enterprise stated that the apprenticeship method helps to manage unexpected problems by training individuals, albeit a long period is required to obtain proficiency.

Mentoring is a critical method that requires modification of the employees' attitude to develop into a proficient practitioner (De Janasz and Sullivan, 2002; Allen *et al.*, 2004 and Emmerik, 2004). This method focuses on the improvement of business by transferring individuals' (mentors') advanced experience and knowledge to employees (Ragins and Cotton, 1999; and Emmerik *et al.*, 2005). In this technique the mentor plays the role of both the content expert and the process consultant (Swieringa and Wierdsma, 1992). An interviewee from a medium-sized enterprise stated that the mentor's skills helped them to improve their reflection process, and delivered knowledge to senior employees as to how to assess their suggested solutions in activities. Another interviewee highlighted that the method of mentoring increased the skill and creativity of their staff in uncommon business difficulties. In two organisations, the senior managers of the companies were mentors and responsible for staff training. They taught risk analysing processes to new employees to enhance their skills in the process.

Uher and Toakley (1999), and Lyons and Skitmore (2004) explored that both individuals and firms in the construction industry present a moderately strong commitment to cultural change by actively supporting new management concepts and strategies. While the construction industry is undergoing change, the rate of change appears to be slow. The main obstacle identified is the low level of knowledge and skill, which are caused by lack of commitment to training. Five interviewees confirmed this cultural issue and stated that the industry has to improve its commitment to training, if it is to take full advantage of risk management. The outcomes indicate that the nature of training provision for risk management within SMEs in the construction industry is primarily based on in-house, on-the-job training with the practise of Job Instructional Technique (JIT), Apprenticeship and Mentoring.

FUTURE TRAINING FOR RISK MANAGEMENT WITHIN SMES

The last question of the interview assessed the nature of future training for risk management within SMEs in the UK construction industry. In this study, the participants outlined the similar method of training for the future. Twenty-two out of 30 interviewees determined the in-house, on-the-job training method for future risk management training. Eight participants mentioned they would prefer to have short and brief external courses rather than in-house trainings. They specified case studies in external training helped them understand the benefits and challenges of other SMEs who were successful in risk management implementation and practice. They believed that external training courses facilitated by specialists deliver more opportunities for trainees to share knowledge and experience within seminars and group discussions.

All interviewees specified the importance of risk management training within organisations. They suggested that future risk management training needs to: be time and cost effective; focussed more on particular aspects of projects; geared with projects' activities; and formalised training programmes (Table 4).

Table 4: The Nature of Future In-house Training for Risk Management

Future In-house training for RM need to:	Small	Medium	Total	Percentage
Be time-effective and cost-effective	12	9	21	70%
Focus on particular aspects	8	9	17	57%
Gear with work environment	3	11	14	47%
Formalise training programme	2	3	5	17%

The data in Table 4 present that 70% of SMEs in this study desired to have time-effective and cost-effective training courses in the future. They indicated that trainings would have to meet their allocated time and budget resources. A manager from a small-sized organisation stated that risk management training should be an in-house training, but it would totally depend on the cost and how much time would be taken. For in-house training, the organisation needs to have sufficient number of trainees to justify the financial input. Another project-manager from a medium-sized company outlined; *“the problem is of course how to find time and where to fit trainings within the working days of an employee”*. SMEs mainly suffer from lack of time and budget in their projects; however, they need to have right skills within the organisation. They realise that training helps employees to relate their activities to risk management and match their tools and techniques with their duties.

Time and cost effectiveness factors were followed by the focused training programme for risk management within SMEs. 57% of participants stated that training in risk management should focus on particular aspects of projects. Training through a focused in-house training could provide in-depth information (by case studies and sample sites); however, external trainings typically discuss general aspects of risk management. A focused training programme supports employees to have a practical visualisation of what a risk represents, also helps SMEs to identify and eliminate relative risks in their work. This type of training is more beneficial for senior staff with particular knowledge and experience.

Fourteen out of 30 participants specified that future training courses had to be geared to organisational working environment. This factor presented the impact of risk management on SMEs. 47% of SMEs had difficulty in understanding the connections

between risk management outcomes and their activities. In-house and on-the-job trainings link objectives of the business with risk management processes. Employees need to see how risk management and risk analysis outcomes could affect their activities. A specific example by an expert based on the organisation's business environment is more tangible than an irrelevant site simulation in an external seminar or conference. A senior manager from a medium-sized company stated that involved risks in a project need to be considered in time and matched against cost management plans, and need to be measured in each related activity. This process is known as the Risk Break-down Structure (RBS) that could be obtained through a geared risk management process. A geared risk management training assists staff to relate what they have been taught and what is actually happening on the site. Furthermore, the discussion on the nature of future training specified formalised training programmes for risk management. 17% of the participants indicated that a formalised training programme within the organisation would be more beneficial than irregular training. Formalised training with determined mission and vision in the organisational business plan can provide a range of useful information that would improve individuals' skills and knowledge.

The result of the current study along with the views of Mathieu *et al.* (1992) and Armstrong (1996) in organisational training programmes indicated that developing risk management training needs an inclusive consideration of learning theories. Antonacopoulou (1999) emphasised that learning theories need to be assessed with employees' training requirements, and have to consider the involved factors of adult learning (Harrison, 2000 and Kepczyk, 2001).

CONCLUSION

On the basis of a survey with the UK construction SMEs having adequate knowledge and experience of construction management, training provisions for RM was discussed. The results outlined that the existing risk management training programmes largely review the general concept of risk management without considering the practitioners' characteristics and requirements. The content analysis specified that majority of SMEs preferred to have in-house and on-the-job training for risk management. This type of training enables SMEs to focus on a particular aspect of each project. It also connects the risk management processes with the organisational activities that facilitates understanding of the benefits and advantages of the process.

Risk management training within SMEs is a complex and context-embedded activity. It requires a full consideration of the organisational characteristics including the system of management; level of resources; degree of employees' knowledge; and objectives of the organisation. In SMEs, the training of risk management should focus more on creating the learning environment that supports employees to improve productivity by controlling the risks of activities. Review of the principles in adult learning specified the needs of the future training in risk management, which could assist to improve the organisational competitiveness.

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MAKING SENSE OF CORPORATE SOCIAL RESPONSIBILITY STRATEGIES IN CONSTRUCTION ORGANISATIONS IN THE UK

Ankit Singh¹, John Connaughton and Richard Davies

School of Construction Management and Engineering, The University of Reading, Reading, UK

Corporate Social Responsibility (CSR) has been conceptualized in a variety of ways and interest groups approach the subject differently. These variations have been observed in the way construction organisations in the UK report on their CSR activities. Research into CSR practices has used annual CSR reports to demonstrate the differences in reporting practices across geographies and sectors. However, what many of these studies have not explored is how reporting CSR practices can provide an insight into the evolution of CSR within these organisations. This paper adopts a sensemaking perspective to explore how construction organisations have labelled and categorised CSR in their annual CSR reports and if these have evolved over time. The annual CSR reports are treated as products of CSR related sensemaking processes within the organisations. A desktop study was conducted of annual reports from 2009-2013 of three large construction organisations in the UK. The data from these reports was analysed and the evolution of CSR within these organisations was plotted on the basis of labels and categories each individual organisation assigned to CSR. The study reveals that these labels and categories are individual to the organisation. Furthermore, the study shows that the labels and categories evolve and change over a time period, thus hinting at an active ongoing CSR sensemaking process within these organisations. An important observation is that the organisations have shifted from CSR to sustainability reporting. Elements of sensemaking theory are applied as a theoretical lens for explaining how the evolution of CSR has occurred within these organisations. This study forms the initial part of a larger piece of work on understanding the dynamics of CSR strategies in large construction organisations

Keywords: corporate social responsibility, CSR reporting, labelling, sensemaking.

INTRODUCTION

The concept of Corporate Social Responsibility (CSR) has been highly debated and researched particularly in the last thirty years. The subject has been conceptualized in a variety of ways by interest groups that have approached the subject differently (Carroll and Shabana 2010). The lack of a consistent approach to CSR has been attributed to the lack of synergy in the manner in which the meaning of CSR has been articulated by CSR theorists and practitioners (Dahlsrud 2008) and this has led to several authors arguing that CSR is an ambiguous term that can mean anything to anybody and is therefore meaningless (Frankental 2001). So far, mainstream and construction research into CSR has adopted a mainly normative approach to simulating what socially responsible behaviour of organisations should be. Furthermore, a large section of the CSR mainstream literature is of a quantitative

¹ ankit.singh@pgr.reading.ac.uk

nature and has focused on establishing a business case for organisational engagement with CSR (Weber 2008; Carroll and Shabana 2010). These studies have primarily attempted to examine the link between corporate performance and CSR engagement. However, these studies have contributed little in the way of understanding the organisational processes that shape the interpretation of CSR for individual organisational purposes (Nijhof and Jeurissen 2006).

In recent times in response to the growing public awareness and sensitivity to the responsibility of business organisations to society, business organisations are increasingly keen to demonstrate their commitment to CSR. Annual CSR reports are seen by both businesses and their stakeholders as a key mechanism through which business organisations can demonstrate their commitment to CSR to their shareholders, customers, employees, public at large and the government (Jones *et al.* 2006). The ambiguous nature of CSR coupled with pressure on organisations to engage in CSR has meant that organisations have had to interpret the concept of CSR to suit their needs. Some of these differences in interpretations have been observed in the comparative studies of organisational annual reports. Studies such as Kotonen (2009) for instance have explored CSR reporting practices of organisations and found that organisations' CSR reporting practices tend to be heavily influenced by the social and cultural context. This is despite the introduction of common reporting guidelines such as the Global Reporting Initiative (GRI). Kotonen (2009) found that organisations mobilize the concept of CSR differently to suit their own unique needs and requirements. Heijden *et al.* (2010) have argued that the process of translating the general concept of CSR for operational purposes is distinctive to each organisation. Based on this perception, this paper investigates the individual nature of CSR in construction organisations from the starting point that each organisation gives its own meaning to the concept of CSR.

Several authors in CSR empirical studies have used sensemaking theory. This has been applied to a range of subjects that include: CSR, new venture creation, IT driven knowledge and technology, innovation and decision making processes (Gioia and Chittipeddi 1991; Weber and Glynn 2006; Heijden *et al.* 2010; Green 2011; Sergeeva 2014). These analyses regard sensemaking as a generally applicable process Weick (1995) advocates that sensemaking is a universal process. However, Heijden *et al.* (2010) believes that searching for the meaning of CSR within organisations can be approached in many different ways and that the process of CSR sensemaking is specific to the organisation in question. Authors such as Cramer (2006); Basu and Palazzo (2008) have identified sensemaking as a useful research perspective that can be used to understand how the concept of CSR is interpreted and operationalized by organisations.

CSR from a sensemaking perspective can be defined as an interactive social process in which the meaning of CSR is systematically organised and reorganised by a network of organisational actors who create and recreate an individual and collective shared frame of reference in relation to CSR objectives, activities and results (Nijhof and Jeurissen 2006).

Construction specific literature on CSR has attempted to model socially responsible behaviour of organisations based on a rather normative approach and has been largely inconclusive (e.g. Petrovic-Lazarevic 2008; Kornfeldová and Myšková 2012). The understanding of how CSR is interpreted and implemented by construction organisations can gain significantly from a sensemaking perspective as it brings into

focus the context that leads to the selection of CSR strategies. Looking at CSR from a sensemaking perspective examines CSR as an evolutionary processes that assumes that different agents act and react upon one another (Weick 1995). Such an approach to CSR means focusing on the dynamic social processes that drive the development of CSR within organisations (Nijhof and Jeurissen 2006).

Viewing the identification and classification of CSR as part of a sensemaking process is a relatively new research approach (Nijhof and Jeurissen 2006; Heijden *et al.* 2010). The representation of annual CSR reports as products that can be used to demonstrate characteristics of a wider sensemaking process, is central to this article. These reports are seen as a useful starting point in exploring CSR sensemaking processes as they provide an overview of CSR priorities that each organisation has arrived at through their sensemaking. It is argued that the annual CSR reports represent the sense that organisations have made of CSR explicitly in the form of labels and categories of CSR that they address.

This paper therefore takes the first step to describe and explore CSR as a sensemaking process within construction organisations and in particular to examine how organisations have labelled and categorised CSR in their annual reports and if these labels have evolved over time. This review of annual reports forms the first stage in a wider study of the CSR sensemaking processes in construction organisations. As part of the qualitative research design, for that wider study a conceptual framework is developed that helps explain the data from annual CSR reports and how it links to a wider sensemaking process that leads to the production of these reports. The conceptual framework is based on some of the key assumptions of Weick's sensemaking theory.

TOWARDS A SENSEMAKING PERSPECTIVE OF CSR

Sensemaking is a process by which individuals or groups interpret, produce and assign a meaning to phenomena. It is through the processes of sensemaking that people enact the social world, creating it through verbal descriptions that are communicated to and negotiated with others (Weick *et al.* 2005; Brown *et al.* 2008). In this way organisations may be seen as products of day-to-day interactions of its members. Prevailing organisational forms are an amalgamation of past decisions and solutions that have successfully worked, without ever having arrived at one best way. The concept of sensemaking when applied to CSR strategies highlights its organisation specific nature. It is contended that people within the organisation, influenced by organisational, individual and social contexts make sense of what they perceive and act out a meaningful picture. Thus in that process they construct their own enacted environment. Annual CSR reports are seen as products of a CSR sensemaking process that are arguably produced for internal and external consumption to demonstrate the organisational sense of CSR. Sensemaking therefore involves a constructivist ontology and assumes that reality does not exist independently of our cognitive structures, but it is socially constructed (Weick 1995).

CONCEPTUAL FRAMEWORK FOR ANNUAL CSR REPORT SENSEMAKING

This paper approaches the annual reports as a product of a wider organisational CSR sensemaking process, that is essentially frozen at a particular moment in time (Weick 1995). It is argued that the process of production of the annual CSR reports involves organisational actors placing boundaries around the flow of the CSR sensemaking

process, whilst isolating moments and cues in the form of labels and categories that help organisational actors make sense of a specific time period in order to enact the annual CSR report. It is further argued that CSR labels that are used within the annual reports to define and map the area of CSR addressed by the organisation, are generated by a specific organisational context and are communicated to a target audience (Morsing and Schultz 2006). These labels describe what CSR means to the organisation the meanings and interpretations associated with these labels may change with time. Elements of sensemaking such as the concepts of labels, categories and communication are introduced below and are used to identify and analyse the data from annual CSR reports.

Sensemaking is Ongoing

The process of sensemaking is in continuous flow within the organisation, it is only when sensemakers attempt to place a boundary around some portion of that flow, does it become an event (Weick 1995). Weick explains that we are constantly making sense of what is happening around us but in order to make sense of the current, we isolate moments and cues from this continuous sensemaking (Weick *et al.* 2005). The notion of ongoing sensemaking refers to the idea that sensemaking neither starts a fresh nor stops cleanly. However this paper argues that the production of an annual CSR report functions as a temporary event or an interruption to the CSR sensemaking flux within the organisation. It triggers a sensemaking phase wherein organisational actors focus on some elements within the wider sensemaking flux, guided by rules and regulations in order to extract cues and construct an account for their CSR commitment over the year (Mills *et al.* 2010; Weick 2011).

Sensemaking Cues

In order to focus on the meaning of sensemaking and give it substance, Weick (1995) recommends drawing upon vocabularies that form the content of sensemaking. This is based on the assumption that people draw upon frames of references to prompt their understandings, these frames of references are derived from past moments of socialization, while these prompts or cues are results of present moments of experiences (Weick 1995). Weick states that the content of sensemaking is determined by the connection between the prompts or cues and the frame of reference.

Labelling and categorizing

In order to stabilize the streaming of experience sensemakers label and categorize the organisational phenomena. According to Chia (2000) labelling works through a strategy of “ *differentiation and simple-location, identification and classification, regularizing and routinization [to translate] the intractable or obdurate into a form that is more amendable to functional deployment*” (p.517). In the process of organising functional deployment requires that the sensemaker imposes labels on interdependent events in ways that would suggest plausible acts of managing, coordinating and distributing. Therefore the manner in which these events are envisioned kick-starts the work of organising as events are bracketed and labelled by the sensemaker to find common ground with others around them. Weick (2010) explains that in order to generate common ground among the actors, the labelling and bracketing is designed by the sensemaker to ignore cognitive differences between actors in order to generate repeatable behaviour. Tsoukas and Chia (2002, p.573) explain,

“ For an activity to be said to be organized, it implies that types of behaviour in types of situation are systematically connected to types of actors.... An organized activity provides actors with a given set of cognitive categories and a typology of actions. A crucial feature of labelling and its categories and types is their plasticity ”.

The categories have plasticity as they are socially defined (by the sensemaker in social context of other actors) and because they are adapted to local circumstances and have a radial structure (Tsoukas and Chia 2002). As the sensemaking process unfolds activities may be re-labelled, Weick (1995,p.31) suggests that when sensemakers enact they:

“Undertake undefined space, time and action, and draw lines, establish categories, and coin new labels that create new features of the environment that did not exist”.

Sensemaking is comprised of sensegiving

Sensemaking is comprised of a notion of “*sensegiving*”, that is directed by the sensemaker at external parties whose perceptions are held to be important and hence worth influencing (Weick *et al.* 2005). Sensegiving is a related process to sensemaking by which sensemakers attempt to shape the sensemaking processes of others (Gioia and Chittipeddi, 1991). Particularly in an organisational context, it is this cyclical processes of sensemaking and sensegiving that lead to an iteratively developed set of shared meanings and actions (Weick *et al.* 2010). The idea that sense is collectively pooled is fundamental for organisational sensemaking, as organisations are viewed as networks of “*inter-subjectively shared meanings*” (Brown *et al.* 2008, p.1038). It is argued that during that the production of annual CSR reports, who the target audience is plays a key role in guiding the selection process during the production of the annual CSR report (Heijden *et al.* 2010). CSR annual reports are seen as an expression of sensegiving, wherein the shared sense that the organisation has made of CSR is communicated to its stakeholders and a wider audience. Studies such as Castelló and Lozano (2011) have identified that through annual CSR reports organisations highlight their identities and resources to their stakeholders thus leading to a distinctive differentiation of CSR strategies. Furthermore this forms a key part of sensegiving where through their annual CSR reports organisations choose to convey specific issues in order to influence their stakeholders that the organisations perception of CSR is legitimate.

Sensemaking is Enacted

Within the sensemaking process, action is used by sensemakers as a means to gain some sense of what they are up against. They do this by asking questions of others within and outside the organisation or by building a prototype to evoke reactions or by making a declaration to see what response it receives or probing something to see how it reacts (Weick 1995). It is through these actions that the sensemaker makes sense of their experience within an environment, thus their sensemaking can either be constrained or created by the very environment it has created (Mills *et al.* 2010). Annual CSR reports are arguably produced by the organisation to demonstrate their commitment to CSR and enhance their credibility as a socially responsible organisation (Jones *et al.* 2006).

METHODOLOGY

The following section explains how the sensemaking perspective informs the methodology. For this study, qualitative methodology is used to address the research question. While empirical research into CSR has primarily been done from a

quantitative stand point, qualitative techniques are common place in the study of sensemaking in organisational research (Heijden *et al.* 2010). Central to this paper is that organisational CSR sensemaking processes are ongoing and constantly keep evolving as sense is made. Using key concepts of from sensemaking theory in particular, labelling and categorizing the CSR reports from the selected organisations were analysed

The limitations of the desktop study are recognized particularly in the area of CSR rhetoric. The annual CSR reports are not viewed as being a democratic representation of the sense that organisations have made with regards to CSR. However it is argued that the labels and categories within the annual CSR reports provide an insight into the boundaries within which the organisation deals with its CSR commitments. The evolution of the labels and categories help in identifying how the organisations have continued to make sense of CSR over the given time period.

The construction organisations chosen for this purpose have been selected for the following firstly, they had an established track record of engaging with CSR for a minimum period of five years, secondly, they are large construction organisations of comparable sizes, in terms of employees, projects and turn over and have the resources to engage in CSR related activity (Heijden *et al.* 2010). The empirical data was analysed using the annual CSR reports that covered a period of five years from 2009 until 2014. The reports were analysed on the basis of the different labels the companies used to address CSR. The reports were analysed with the primary focus of identifying the labels and categories that the organisations used to define CSR (see table 1) and to explore if they evolved over time.

OBSERVATIONS

Labelling of the reports

From the analysis of the reports it is observed that a range of labels are used by the three organisations to identify and label CSR. For example, company A initially labels it as corporate responsibility report. After the label stabilises for a period of three years as it is addressed as such consistently. It is reviewed and made sense of again and is addressed as CSR as part of their annual report, this is eventually revised and relabelled as sustainability report the following year. Company B shows a similar evolution as it recognises CSR as part of its annual report, this meaning appears to stabilise as it is utilized over a period of three years and is then relabelled as a sustainability report. Company C, shows an evolution from CSR to corporate responsibility to then addressing CSR as either responsibility or as part of a wider social issue.

Categories associated with the labels

Each of the three organisations categorise their labels very differently. For example, Company A initially categorises the label of corporate responsibility on the basis of social and environmental areas such as boosting the skills of their employees, charitable giving, reducing carbon emissions and minimizing waste. While company B on the other hand initially categorizes CSR on the basis of health and safety, people and environmental areas and company C categorizes on the basis of people, health and safety, environment, community involvement, customer suppliers and corporate governance. These labels and categories appear to address similar broad areas of CSR however each organisation chooses to address them in their own individual manner, choosing different categories and priorities under these labels.

It is also observed that as the labels evolve the categories under the labels change to reflect that evolution, for example when the CSR label of company A from CSR is relabelled as sustainability review, the categorisations change from addressing just social and environmental categories to addressing sustainability categories such as economic, social and environmental. Company B shows a similar pattern when their labels evolve from CSR to sustainability their categories change from addressing health and safety, people and environmental issues to a wider range of sustainability issues. Subsequently in the following year this is re categorized under people, planet and profit. The report labels and categories of Company A and B change to reflect a change in their organisational sense of CSR, here organisations move away from the label of CSR to sustainability.

Table 1 : Time line of CSR labels in the three construction companies.

	Year	Report Label	Type of Report	Broad Categories Addressed
Company A	2009	Corporate Responsibility report	Standalone	Social and environment
	2010	No report	No report	No report
	2011	Corporate Responsibility report	Standalone	Social and environment
	2012	Annual report	Sustainability section as part of combined annual report	Sustainability- Social and environmental categories
	2013	Sustainability Review	Standalone	Sustainability- Social and environmental categories
Company B	2009	Annual Review- Corporate Social Responsibility section	CSR section as part of combined annual report	Health and safety, people, environmental
	2010	Annual Review- Corporate Social Responsibility section	CSR section as part of combined annual report	Health and safety, people, environmental
	2011	Group sustainability report	Stand alone	Approach to sustainability, Safe workplace, developing talented employees, Reducing waste, reducing energy consumptions and carbon emissions, improving sustainable procurement, supporting local employment,
	2012	Sustainability Report	Stand alone	People, Planet and Profit
	2013	Sustainability Report	Stand alone	People, Planet and Profit
Company C	2009	Annual report	CSR section as part of combined annual report	People, Health and safety, environment, community involvement, customer and suppliers, corporate governance,
	2010	Annual report	Corporate responsibility section	Health and safety, community involvement, people, environment, customers and

		as part of combined annual report	suppliers, corporate governance
2011	Annual report	Responsibility section	Business risks- Financial risks, health and safety, the environment, human resources, community involvement.
2012	Annual report	CSR as part of low carbon economy.	Business risks- Financial risks, health and safety, the environment, human resources, community involvement.
2013	Annual report	CSR as part of community involvement.	Business risks- Financial risks, health and safety, the environment, human resources, community

CONCLUSIONS

The research question of this paper focused on exploring how organisations label and categorise CSR in their annual reports and if those labels change or evolve over a time period. This paper demonstrates that the three organisations with the different ownership structures label CSR differently. The change in labels from CSR to sustainability indicates a change in the organisational sense and perception of the concept of CSR, which seems to gravitate towards that of sustainability. The evolution and stabilising of labels and categories in the annual CSR reports of the three construction organisations has indicated the presence of a wider ongoing CSR sensemaking process within the selected organisations.

These labels and categories provide a useful initial insight into the manner in which these organisations have interpreted the concept of CSR. The fact that these organisations in their reports include certain labels and categories while excluding others demonstrates in part the sense the organisation has made of CSR. This organisational sense does not necessarily accord with all views of individuals or internal stakeholders and in turn this does the raise the issue of who the key CSR decision makers are and what influence they have on the sensemaking process. However it must be recognized that these reports are issued on the behalf of the organisation and reflects the organisational sense of CSR and not individual sense.

There is also the issue that part of the sense made in order to produce the annual CSR reports includes an element of rhetoric. It has been argued that annual CSR reports are a representation of what the organisations believe the market wants to hear (Castelló and Lozano 2011) and are a means to promote themselves. However, when viewed from a sensemaking perspective it is part of the sense that organisations make of CSR in that they choose to promote themselves in a certain way. As argued by Alvesson (1993) rhetoric is a critical cultural and symbolic resource for an organisation to develop and convey the sense that they have made.

Furthermore, it is argued that once these reports are published by the organisation they become the defacto sense of CSR, which is then pursued by the organisation i.e. organisations pursue the objectives defined under the labels and categories that are outlined in these reports rather than what is not documented.

It is recognized that varying organisational contexts cannot be adequately reflected without exploring the organisational sensemaking processes that influence the formation of these labels and categories. However while these reports have a marketing function, through the labels and categories these CSR reports help define a

rough boundary around the issue of CSR for the organisation to work within. Furthermore, it is recognized that further research is needed to explore why the labels and categories have evolved in the manner they have.

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MAKING SENSE OF CSR IN CONSTRUCTION: DO CONTRACTOR AND CLIENT PERCEPTIONS ALIGN?

Greg Watts¹, Andrew Dainty and Scott Fernie

School of Civil and Building Engineering, Loughborough University, Leicestershire, UK

The achievement of Corporate Social Responsibility (CSR) objectives is increasingly being viewed as of key importance in the procurement process of public sector construction projects. As such, main contractors and public sector clients are increasingly interested in and keen to espouse the benefits of CSR strategies and their measurement. However, it cannot be assumed that both sets of broad stakeholders share a common understanding of what CSR means, what it constitutes and how it can be used to serve vested interests. This research aims to provide a deeper understanding of the motivations for stakeholders across the public procurement divide to participate and engage in CSR related to the procurement and delivery of construction projects. In-depth semi-structured interviews with practitioners from main contractors and various public sector client organisations were conducted. These formed the basis of analysis in order to explore how each constituency made sense of CSR. The theoretical frame used to analyse the data drew from Weick's (1995) sensemaking approach and revealed similarities and differences in the understanding of CSR between the constituencies on either side of the contractual divide. The importance of, and motivation for, CSR participation is shared by constituencies, but an agreed definition couldn't be reached, and what 'counts' as CSR in one geographical location for one client, may not count for another. These findings challenge simplistic assumptions about CSR and highlight significant limitations on what CSR can deliver via public sector procurement processes.

Keywords: CSR, procurement, sensemaking, strategy.

INTRODUCTION

Arguably, the construction industry has experienced major changes over recent years, both in terms of the value of work available since the economic recession and the demand from clients to get 'more for less'. It is said the drive to achieve 'more for less' can be attributed to public sector clients as they use the considerable size of their contracts as a powerful driver for their increasing concern with achieving CSR objectives (Varnas *et al* 2009) in addition to traditional procurement goals of time, cost and quality.

Research has shown that the size of the UK public sector to private organisations is substantial (Loader 2015). Arguably, if private organisations want to continue to successfully win public sector work they need to provide evidence that not only do they have CSR strategies in place, but that these CSR strategies align with those of the client (Snider *et al* 2013). However, the literature is awash with persistent conflicts and debates in defining what CSR actually is (Petrovic-Lazarevic 2008) with the concept now becoming an umbrella term covering a variety of topics (Freeman and

¹ g.watts@lboro.ac.uk

Hasnaoui 2011). It is unsurprising that CSR is likely to mean different things to different people (Lindgreen and Swaen 2010).

Notwithstanding problems in defining CSR, there remains a need for contractors and public sector clients to align CSR strategies with their client's expectations. Research is required to enable an understanding of how such alignment can be encouraged and better developed to provide wider societal benefits in ways that yield successful business outcomes for contracting organisations. This paper contributes to this gap in knowledge by exploring the ways in which contractors and public sector clients make sense of the CSR construct. A sensemaking lens is adopted (cf. Weick 1995) to gain an insight into the multiple interpretations of CSR and how these differ across the public procurement divide.

CSR

For many years the debates in the field of CSR were focused, unsuccessfully, around reaching an agreed definition with a plethora of definitions provided from all manner of sources (Blowfield and Murray 2011). Whilst CSR has increased in importance an agreed definition hasn't been reached (Valiente *et al* 2012), providing the basis for misunderstandings across academia and industry (Lindgreen and Swaen 2010). Research by Griffith (2011) concluded that organisations use the term CSR so often it is now part of common business lexicon. This was confirmed in recent research by Madрахimova (2013) who argues that the concept of CSR is now universally accepted as a requirement of organisations and expectation of clients.

Despite its acceptance into the vernacular of the business lexicon, Freeman and Hasnaoui (2011) concluded that CSR has become an umbrella term embracing a wide array of definitions and components. These elements can include the economic, legal, ethical and voluntary features of an organisation's behaviour (Carroll 1983), society (Petrovic-Lazarevic 2008), and the environment (Arjalies and Mundy 2013). Visser and Tolhurst (2010) also press the importance of geographical context as a factor when defining CSR in that applicable CSR activity is often defined by its location, in that it needs to occur in an area required by those judging the success of the activity.

Debates have persisted around the motivation for organisations to engage in CSR for a long time and largely include the question of whether they do so for financial benefit or are driven by altruism, with Oberseder *et al* (2013) arguing that some organisations embrace CSR whilst others use it for PR. However, regardless of the organisational motivation, research has found that there are myriad benefits that can be accrued via participation in CSR including increased reputation (Brammer *et al* 2007), increased appeal to potential employees (Backhaus, Stone and Heiner 2002), and most potently, increased competitive advantage (Arjalies and Mundy 2013). Therefore it can be concluded that CSR participation is advantageous for organisations. However, research by Snider *et al* (2013) illustrates a challenge for contractors to realise these benefits of CSR participation, as he reports contractors need to align their perceptions of CSR with that of the clients in order to successfully procure contracts. This potentially has a profound impact on the public procurement process, and suggests an alignment of CSR views is a prerequisite for contractor success.

However, in addition to the reported benefits of CSR participation, there have always been arguments against organisations engaging with CSR, with the focus of organisations being solely upon profit generation and not social responsibility. This is illustrated by Inoue and Lee (2011) who highlight the belief that if CSR does not lead

to financial benefit then it should not be worthy of investments of an organisations time and money. Indeed, Green (2009) suggests that there is a legal requirement of public limited companies to maximise profit for its shareholders, which presents a real tension at the centre of the CSR concept, as a study by Patari *et al* (2014) finds no relationship between CSR and FP. However, counter arguments have also developed which directly and indirectly link an organisation's CSR participation with its financial performance (Saeidi *et al* 2014). If correct this serves to reposition traditional arguments against CSR participation further reinforcing the rationale for contractors that engaging in CSR is beneficial for work winning in the public sector (Uttam and Le Lan Roos 2015). This of course places an emphasis on CSR as an important element to be considered by both the public sector and the private sector contractors within the public sector procurement process.

CSR AND PUBLIC SECTOR PROCUREMENT

The public sector itself has been described as an ambiguous term, but this paper adopts as a definition proposed by Uyarra *et al* (2014) who define it as including the NHS, national and local government. According to the HM Treasury (2010) these three public body groups contribute to around 90% of public procurement spending, a figure that equates roughly to research carried out by Loader (2015) who argues that the size of UK public procurement is substantial with around 83% of public spend coming from the three sectors mentioned above. When measured by value of construction output the entire public sector accounts for around 26% of UK construction work, and during 2008 and 2009 increased at a time when private sector work reduced (Rhodes, 2014). Therefore we can see that the size and consistency of the public sector offers a degree of reliability and certainty to contractors.

Traditional procurement criteria of construction works have been on a competitive basis revolving around time, cost and quality (Wong *et al* 2000), with the lowest priced contractor usually awarded the works. However, over the last few decades public construction procurement has evolved in two main ways: firstly an increase in private sector collaboration (Jost *et al* 2005), and secondly, that procurement requirements of public clients has a more social and environmental focus (Wong *et al* 2000). According to Powell *et al* (2006) this approach to procurement has been criticised for focusing entirely upon environmental issues, and so was replaced by the term 'sustainable procurement' which includes considerations for the environment, society and community (Uttam and Le Lan Roos 2015), all of which are elements pertaining to CSR (Snider *et al* 2013). This confirms the increasing importance of CSR in public procurement, a fact that is also evidenced in the growing weighting CSR has in tender documents, which from not being a factor, is currently reported to be worth around 10% (Varnas *et al* 2009; Uttam and Le Lan Roos 2015). Such weighting can have a significant effect on which tenders are successful depending on the CSR participation of the contractor. Despite the ambiguous nature of CSR there is clearly no doubt that engaging with its objectives is a pre-requisite to winning public sector work in contemporary markets.

SENSEMAKING

Sensemaking is a cognitive process individuals experience when trying to understand new and complex information, and consists of seven key characteristics (Weick *et al* 2005). It is in many ways a separate body of literature to CSR, but has been adopted as a lens to understand the views and opinions of individuals and how meanings are created (Angus-Leppan *et al* 2010). The foundation of sensemaking is identity

construction, or how an individual's background and experience influences their ability to make sense of future encounters (Ericson 2001). A second characteristic is retrospective, whereby individuals reflect on the experience, which leads to a better understanding being gained (Angus-Leppan *et al* 2010). The characteristic of enactive of sensible environments is concerned with how the individual influences their environment, and then how in turn this environment influences how the individual makes sense of information (Seligman 2006). It is also noted that the 'making of sense' is a social process where sense of a situation is only fully made when meanings are discussed and agreed upon (Seligman 2006). Another characteristic of sensemaking is that it is an ongoing and continuous process as an individual will always make further sense of new and old situations experienced; cues are extracted from their environment by an individual to help make sense of information (Seligman 2006). The final characteristic of sensemaking is driven by plausibility rather than accuracy and highlights how, when 'making sense', individuals can settle for information that is plausible but not necessarily accurate (Weick *et al* 2005). According to Van der Heijden *et al* (2010) CSR is implemented through the setting of a strategy, with CSR becoming a form of strategic change which individuals make sense of, triggering the process of sensemaking (Bartunek *et al* (2006) By utilising sensemaking theory, and structuring interviews around the seven characteristics, it will allow for an in depth understanding of both contractor and public sector client's perceptions of CSR to be gained.

METHODOLOGY

The search for a deeper understanding of individuals' views on CSR requires an interpretivist methodology, which is concerned with ascertaining the individual's interpretation of CSR from their own frame of reference (Blaxter *et al* 2010). This research therefore explores individual human knowledge, and requires qualitative data to establish an understanding of, and provide clarity on, the context in which an individual's unique insights and interpretations are formed (Barbour 2008).

Public sector bodies were identified through an online search of different geographical areas of the UK. The public bodies were separated into three categories: defence and healthcare, local government, and housing. A purposive sampling method then ensued to select each body for interview participation. An initial review of the public bodies' website for an appropriate contact or department was conducted, before contact was made to explain the purpose of the research, and a suitable candidate was sought to ensure all responses would be relevant (Bryman 2012). The websites of the top 20 main contractors by turnover were reviewed for information on their public sector presence. Those without an advertised public sector presence were removed and a random sampling method occurred to select from those remaining.

Due to the ambiguity and breadth of the different understandings as to what CSR constitutes, interviews were utilised as they allowed a detailed insight to be gained from each of the participants (Creswell 2013) as to their understanding of CSR, and the motivations for their organisations participation in CSR activity. Semi-structured interviews allowed an in-depth perspective to be gained (Bryman 2012) as long responses could be elicited (Arjalies and Mundy 2013) using the participants own language preferences (Edwards *et al* 1997; Ericson 2001). Face to face interviews allowed for more complex questions to be asked (Kothari 2004) with studies also showing that they result in greater participant-interviewer relationships due to the presence of effective nonverbal communication (Drolet and Morris 2000). Debates

exist over the effectiveness and prevalence of telephone interviews (Kothari 2004; Holbrook *et al* 2003), however, due to the reduced time, diary constraints, and the geographically spread participants, telephone interviews were utilised when it was impractical to arrange face to face interviews (Uyarra *et al* 2014). Fourteen interviews were conducted in total, seven with clients and seven with contractors. Both main contractor and public body interviews were conducted with senior members of staff, with interview questions based around the seven characteristics of sensemaking to purposefully elicit a meaningful dialogue from which the participants' understandings and motivations behind their organisations CSR involvement could be ascertained. From analysis of the interviews, responses were coded under common headings which derived from prevalent discussion points. These discussion points were themselves derived from the questions asked which were framed around the participants understanding of CSR, and which utilised the seven characteristics of sensemaking as a framework for eliciting this understanding and how it was created. This allowed a comparison to occur under the coded headings from the different interviewees whereby differences and consistencies of understanding could be established.

RESEARCH FINDINGS AND LIMITATIONS

The sensemaking lens allowed an in-depth and comparable understanding of individual CSR perceptions to be gained. Analysis and comparison of the interviews found several notable areas of interest. Firstly the interviews confirmed that CSR is indeed of increasing importance to both main contractors and public sector clients in the public procurement of construction works. Interestingly the spectrum of CSR engagement differed dramatically between all organisations interviewed; public clients ranged from minimal CSR requirements in procurement to CSR playing a key deciding factor when awarding work. Between main contractors this spectrum was not as widely distributed, as all contractors believed CSR to be of high importance in procurement. However, a common theme to all responses from both clients and contractors was that the majority believe they are behind the curve when it comes to CSR. They all saw competitors as ahead of them with their CSR demands, engagement and reporting, with this understanding illustrated within the 'social' and 'focused on and by extracted cues' elements of the sensemaking framework, as contractors reported their views derived from discussions internally with colleagues, and information they ascertained from industry media.

When discussing how their respective organisations made sense of CSR, the 'social' and 'enactive of sensible environments' elements of the sensemaking framework played an important role in the understandings individuals formed. Public sector clients commented that all staff members shared a common understanding of the need for CSR, and so were all behind its requirement and implementation. They reported this understanding was promoted and reinforced by the information available across the organisation in internal communications which shared best practice and accomplishments in the form of success stories. Main Contractors did not discuss the same consistency of support from fellow staff, with inconsistent understandings and approaches to CSR shown. Some contractors reported more organisational support than others, and all commented on how this support had increased over recent years which they believed to be a trend across the construction industry, although all contractors mentioned differing levels of organisational resistance. They believed this resistance was in part due to the social environments staff worked in, and how 'pockets' of colleagues perceived CSR as a 'waste of time' and a 'distraction from the job'. This finding contradicts the literature that a benefit of organisational CSR

participation is increased appeal to employees. However, those interviewed did opine this was a reason for their own desire of continued employment with their respective organisation. CSR, it seems, only appeals to employees if they understand the broader advantages that CSR participation can bring.

Generally, there was a consensus across all contractors who were motivated to participate in CSR for two main reasons. Firstly, to improve and give back to society, and secondly, as CSR participation assisted work winning, both responses were always given but the former was constantly highlighted as the most important from the respondents. This closely aligned with public sector clients' understanding for CSR participation, whose primary response was that it is to maximise the benefit of public sector spending for members of the community, reinforcing arguments in the literature. There was also a consensus amongst clients that CSR participation leads to a competitive advantage for contractors, as CSR plays an increasingly important role in tendering, and therefore leads to a competitive advantage, reiterating findings in the literature. The findings show an alignment in opinion of the motivations behind CSR participation for all contractors interviewed, and all clients. This alignment of understanding also extends across the public procurement divide.

However, there was not a shared definition of CSR between contractors and public sector clients, with a disparity in the understanding of what CSR actually is, and how it is made sense of. Both contractors and clients used a plethora of terms to define their understanding of CSR, how it was interpreted, and what it meant to them; reinforcing arguments in the literature that CSR is an umbrella term under which there is little agreement, but that all organisations know what CSR is in relation to their own operations. There was an overlap in some CSR understandings on elements such as environmental and social importance, but the main difference emerged as what 'counted' as applicable CSR participation. The 'grounded in identity construction', 'enactive of sensible environments and 'driven by plausibility' elements of the sensemaking framework provided an insight into how understandings of CSR were formed. In all cases contractors saw their identity as national, and so understood their CSR to be on a national basis. Whereas all public clients were local to only the one area in which they operated, and therefore only valued CSR activity as applicable to procurement if it fell within their geographical remit. This view wasn't shared by five out of the seven contractors interviewed who regularly included all their CSR participation in tenders; even if it bore no connection to the geographical region the client was based. Another potential reason for this difference in understanding geographically applicable CSR can be seen in the 'retrospective' and 'ongoing' elements of the sensemaking framework which showed that for the majority of contractors, their understanding and interpretation of CSR was not an ongoing process, but had in fact been created previously and retained within the organisation. This differs across the public procurement divide from clients who commented that CSR was an evolving concept depending on the needs of their communities.

Due to the office locations of the main contractors and public bodies who agreed to participate in the study, the geographical spread of results was wide. However, a limitation of this research is that it cannot claim to represent an overall nationwide or regional view of main contractor and public body opinions on CSR participation due to the sample size of interviewees. Indeed, the sensemaking element 'grounded in identity construction' showed that all individuals interviewed from contractors saw themselves and their role as heavily CSR orientated, and so a certain degree of bias in

the responses could have been experienced towards an increased CSR awareness which may not be representative of the entire main contracting organisation.

Table 1 highlights the key differences identified between clients and contractors understandings of how they view the construct of CSR.

	Construction Main Contractors	Public Sector Clients
Support from fellow organisational staff	Reported inconsistent and sporadic CSR support from some staff groups. Organisational resistance was highlighted as a result of not understanding the full advantages of CSR participation.	High levels of consistent support from across the organisation. A strong belief and consensus of opinion on CSR participation and motivation was reported.
Definition of applicable CSR activity	All contractors were national and so believed CSR activity to be the same. The majority of contractors believed CSR activity regardless of location would be sufficient for inclusion in tender documentation.	Only CSR activity which fell within the clients' geographical remit was considered applicable when comparing contractor tenders. CSR activity outside of this area was not viewed as favourable.
How an understanding of CSR was reached	From their initial formation, contractors' understandings of CSR remained the same. The understandings were retained within the organisation and were subject to little evolution.	Clients reported an ongoing understanding of CSR which was subjective and based upon the current needs of their local communities.

Table 1: Key differences in contractor / client CSR construct

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE

This study explores the organisational benefits of CSR participation to contractors who bid for public sector work, and the different perceptions of CSR that exist across the procurement divide. The literature argues that confusion still exists over the precise nature and definition of applicable CSR activity, but that it is an agreed and accepted organisation action, which has a positive relationship with competitive advantage. Interviews were conducted with both public bodies and construction main contractors. Sensemaking was found to be an effective lens through which to structure the interviews as it helped elicit insightful opinions and help gain an in-depth understanding of how individuals make sense of CSR, and how the information they receive informs their perceptions. Comparison and analysis of the interviews concluded that CSR was of increasing importance to clients and contractors, but an exact alignment of what the term covered did not exist. A key criteria which was not shared related to the difference in assumptions as to what constituted applicable CSR activity reinforcing arguments in the literature by Visser and Tolhurst (2010) and Snider *et al* (2013). The geographical locality of CSR activity was of high importance

to all public sector clients with activities falling outside of their geographical remit not given as much positive weighting when comparing and awarding public sector works. However, this geographical limitation was not shared by most main contractors who regularly used examples of their CSR activity from outside of the public body's geographical remit in an attempt to secure procurement opportunities. This could have implications for communities which fall within areas where public bodies do not have the same buying power as others, and therefore cannot extract similar CSR outcomes from their supply chains. Future studies could build upon this research further by conducting similar research but focussing upon an example of public procurement in an attempt to add validity, or increase the sample size and number of organisational actors interviewed.

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PUTTING A VALUE ON YOUNG PEOPLE'S JOURNEY INTO CONSTRUCTION: INTRODUCING SROI AT CONSTRUCTION YOUTH TRUST

Jemma Bridgeman¹, Alex Murdock², Peter Maple³, Christine Townley⁴ and John Graham⁵

^{1, 4 and 5} *Construction Youth Trust, Cardiff, UK*

^{2 and 3} *London South Bank University, London, UK*

The challenges measuring social value is not a new concept for the construction industry which is good at measuring costs, timings and efficiency of projects but not the benefits of intangibles such as good design even though design can promote everything from reduced crime to higher productivity (Macmillan, 2005). The measurement of social value has become increasingly important through the enactment of the Social Value Act 2012 requiring public authorities to consider economic, social and environmental well-being when awarding public sector contracts. Social Return on Investment (SROI) is an approach that can be used to measure the social, economic and environmental benefits of an activity by dividing the value of outcomes for stakeholders, by the inputs of the activity leading to the SROI ratio. The research reports on a project at Construction Youth Trust to develop a bespoke Social Return on Investment (SROI) model to capture the value of activities helping young people facing barriers access opportunities within the construction industry. The research examines the primary and secondary research that went into the development of the Trusts bespoke SROI model that was developed in partnership with the construction industry and part funded by construction company Willmott Dixon. Initial conclusions are that SROI is still under development and there are a lot of technical challenges to implementing the approach such as a lack of universal bank of financial proxies and the inability to compare SROI reports. Therefore implementing SROI is currently a time consuming and expensive process.

Keywords: social return on investment, social value, SROI.

INTRODUCTION

The measurement of social value has become increasingly important for the construction industry through the enactment of the Social Value Act 2012 requiring “*public authorities to have regard to economic, social and environmental well-being in connection with public service contracts*” (HMG, 2012). The research reports on a Knowledge Transfer Partnership (KTP) project with a third sector organisation, Construction Youth Trust, to evaluate the impact of its activities helping disadvantaged young people access opportunities within the construction industry. The research reports on the development of a bespoke SROI model for the Trust’s Budding Builders programme which aims to provide young people with practical construction training and work experience opportunities in the construction industry

¹ jemma.bridgeman@cytrust.org.uk

trades. The overarching aim of the research was to produce and embed bespoke, transparent and robust Social Return on Investment (SROI) measures in order to continue to measure the social and financial impact of the organisation. The calculation of social value and social returns on investment is a contested field. The lack of a universal bank of indicators means that SROI currently requires a great deal of research and is time consuming and expensive. Macmillan (2006) suggests there is a need for a common vocabulary for the numerous kinds of value created for stakeholders and a framework to measure value interactions between stakeholders. While the SROI methodology presents a framework to measure value the lack of consistency in financial proxies means it can be argued there is not currently a universal language in SROI measurement. Moreover, the recent Social Value Act Review found that barriers defining social value were a barrier to implementing the Act (Cabinet Office, 2015). The research reports on the primary and secondary research that went into the development of the SROI model at Construction Youth Trust.

It has been argued that there is a clear need for local authorities and clients to take the initiative for training within the construction industry (Chevin, 2014a). The cross party parliamentarians' inquiry examines youth unemployment and the construction industry notes, the downturn in the economy has *"had a devastating effect on construction, with 400,000 job losses"* (Chevin, 2014a: 6). However, the impact of the financial crisis has also led to significant reductions in the recruitment of young people and apprenticeships have fallen significantly. In *"2013 the number of construction apprentices completing their apprenticeship in England fell to just 7,280 half the figure for 2008/09"* (Chevin, 2014a: 6) Hogarth and Gambin (2014: 846) note that apprenticeships in construction are provided *"mainly to young people leaving school and college and thereby play an important role in assisting young people make the transition from school to work. The importance of this...at a time of historically high youth unemployment should not be underestimated"*.

The public sector in the UK has two mechanisms to leverage training and apprenticeships within the construction industry. Firstly, through section 106 agreements these are planning elements designed to ensure developments are sustainable and meet the needs of future generations this can include economic sustainability through the training and employment of local people. Specific contributions include training, employment advice, interview guarantees and work placements" (Chevin, 2014a: 25). Secondly, training and employment can be levered in the procurement process as contractual obligations as part of the Social Value Act. Chevin, (2014) explains that social landlords are more and more using these levers to secure training but these are more isolated incidence of good practice rather than a consistent approach to secure training as part of the procurement process.

The commencement of the Public Services (Social Value) Act requires *"public authorities to have regard to economic, social and environmental well-being in connection with public service contracts"* (HMG, 2012). Arvidson and Kara (2013: 3) explain the intention of this law is to make sure that, *"when awarding contracts, commissioners should consider not just cost aspects of a proposed project or bid but its overall value to the community"*. The 'Social Value Act' Review examined issues affecting the knowledge, understanding, and uptake of social value as well as the impact of the Act not only on the commissioning practices of public bodies but also on the providers and end users of services (Cabinet Office, 2015). The review advises that the challenges defining social value were a barrier to implementing the Act but

conversely found potential for social value to help commissioners achieve value for money within a competitive process. However, in order for social value to be included more comprehensively there needs to be significant development in how social value is measured pointing to the lack of consistency in how outcomes are measured and quantified (Cabinet Office, 2015). Explaining the lack of clarity in social value measurement makes it harder for procurement officers to evaluate the additional value for money claimed by a social value offer (Cabinet Office, 2015). In the periodical *Construction Manager* an article suggests there is general support for the social value approach, particularly if “*it does allow the industry to compete on its sustainability and social credentials rather than price*” noting conversely “*the clamour to ensure return on investment has left firms feeling confused and a tad sceptical*” (Chevin, 2014b).

The calculation of intangibles is not a new concept for the construction industry. Macmillan (2005) explains the genuine difficulty in measuring the benefits of good design because they are intangible. It has been argued that it has been a significant problem for the construction industry that is relatively good at measuring the costs of design and construction but not as convincing at measuring value (Macmillan, 2005). However, it should be asked whether financial measures are an accurate measure of actual performance. If measures are quantitative and simply look at the costs, timings and efficiency we are missing the qualitative dimensions and the impact and the quality of buildings and communities for end users. Pearce (2003: 50) explains that good design can promote everything from “*physical and mental health, to a sense of identity and wellbeing, to good social relationships reduced crime, and higher productivity. Bad design and dilapidated stock has the opposite effect*”.

This research does not attempt to explain how the value of social and non-economic impacts can be measured in construction or measure the benefits of good design. However, they are being used to illustrate this is not a new phenomenon and various approaches have been used. For example, Glasson and Wood (2009) used a Social Impact Assessment to determine the social impact of a regeneration initiative in London. Negative impacts were identified for young people as part of the regeneration of Woodberry Down including being excluded from public spaces such as private courtyards. However, there were also significant beneficial outcomes for equality groups in terms of employment and skills particularly for BME groups and women who were the target group for targeted skills training and employment within the construction industry (Glasson and Wood, 2009).

The measure of intangibles and social impact is not just a problem for the construction industry. There have been a plethora of tools developed to measure impact. Such as equality impact assessments, Genuine Progress Indicator, Results Based Accountability, Quality of Life indicators, SIMPLE social impact assessment, Social Accounting and Audit, Sustainability Assessment Model. This is by no means an exhaustive list but gives some indication of the range of impact measures currently in use. The calculation of social value and social returns on investment is a contested field. While acknowledging the pros and cons of the methods used to measure impact above two methods were seriously considered to measure the value the Trust creates social accounting and SROI. There are similarities between social accounting and SROI both methods use a framework to enable organisations to report on its triple bottom line of social, environmental and economic performance. Social accounting and audit enables an organisation to demonstrate accountability proving they walk the walk as well as talk the talk by examining whether activities meet the mission, vision

and values of an organisation (Pearce and Kay, 2005). It was felt that SROI was the best method for the Trust as an aim of the study was to measure the impact of projects in partnership with the construction industry and community partners. As such it was unnecessary to measure whether the Trust's activities were fulfilling the aims and objectives of the organisation. Instead an approach was needed that explained the value of a project with inputs from and outcomes for various stakeholders and SROI was considered the best approach that would resonate with the construction industry and key funders.

SROI is a framework for measuring a broader concept of value it is a framework based on seven principles *“involve stakeholders; understand what changes; value the things that matter; only include what is material; do not over-claim; be transparent and verify the result”* (SROI Network, 2012: 9). The SROI Network (2012: 8) explains that SROI strives to *“reduce inequality and environmental degradation and improve wellbeing by incorporating social, environmental and economic costs and benefits. SROI is ground breaking as it endeavours to measure and value on what really matters to service users the outcomes of services for them. SROI is not without its critics but it could be argued it is simply a method under development but the inroads the approach is making measuring intangibles should be acknowledged.*

SROI fundamentally is an approach that describes the story of change through measuring social, environmental, and economic outcomes and uses monetary values to represent them. Once stakeholders have identified changes that have happened for them financial proxies are used to value these changes. Then what would have happened anyway, if the activity did not exist, is deducted from these proxies to establish the impact of the activity being analysed. In order to calculate the SROI ratio the net benefits of changes stakeholders identify are divided by the amount invested in the activity. The SROI Network (2012) have put together a framework for undertaking an SROI study that contains six stages identifying key stakeholders, mapping outcomes, evidencing outcomes, establishing impact, calculating the SROI and reporting, using and embedding the report.

Current guidance on SROI does not recommend the comparison of SROI reports. Arvidson et al (2013: 3) note a “tension between the participatory element in the design of each SROI exercise and its use for the purpose of competition”. However, paradoxically SROI reports require a great deal of data to underpin assumptions and SROI practitioner reports are a good source of data. For example, Bates and Yentumi-Orofori (2013: 1) explain that SROI assumptions need to be defensible explaining they used “NEF accredited reports as the source for deadweight, displacement and drop-off figures. We have used Department for Work and Pensions (DWP) and Ministry of Justice (MoJ) figures for costs relating to state benefits and criminal costs” This gives an indication of the amount of research needed to produce a valid SROI study.

One of the reasons that SROI requires so much research is that there is not a universal bank of indicators. The SROI Network has a repository of practitioner reports and is continuing to develop useful tools such as the Global Value Exchange (no date) an interactive website that enables users to upload outcomes, indicators and financial proxies. Therefore, although there is progress towards the production of a standard approach to SROI the approach currently needs organisations to undertake a substantial amount of research to essentially put financial value on intangible measures. Macmillan (2006: 268) suggests the measurement of intangibles in the

context of measuring the benefits of good design requires a need for “*a common vocabulary for the various types of value created for different stakeholders, and a framework for understanding value exchanges between these stakeholders*”. Perhaps SROI is this framework but arguably without the standardisation of proxies the shared vocabulary is missing.

Construction Youth Trust is a registered charity that helps young people overcome barriers to access opportunities within the construction industry. Construction Youth Trust has two overarching programmes Budding Builders and Budding Brunels. Budding Builders is a programme that helps young people overcome barriers to enter employment in construction industry trades. Budding Brunels is a programme that helps young people overcome barriers to access opportunities in the construction industry professions. The Budding Builders programme aims to give young people valuable work experience and an opportunity to learn new skills such as carpentry, tiling, plumbing, painting and decorating and health and safety. The research evaluates the SROI of a practical construction project that is part of the Trust's Budding Builders programme. Practical community projects provide young people with work experience in the heart of their local community.

The SROI model was developed at the Trust is discussed below. The development of the model is generally talked about however a single case study is used to illustrate the development of the model. A forecast SROI study was undertaken of a practical project at the Summerfield Community Centre in Birmingham. The Trust and Willmott Dixon worked in partnership to deliver a practical construction skills course to eight young people. The course culminated in the young people working alongside Willmott Dixon and Construction Youth Trust staff to carry out improvement works at the community centre. The SROI study of the practical project is a forecast one because not enough time had passed to undertake an evaluative SROI. There are two types of SROI analysis forecast and evaluative. Evaluative SROI is carried out retrospectively based on the outcomes that have taken place and forecast, predicts the social value that will be created if activities meet their forecast outcomes”(SROI Network, 2012).

In the SROI model at the Trust outcomes for beneficiaries were divided into two broad categories employment outcomes and soft outcomes. For employment outcomes wages, increased tax take, reduced welfare benefits and improved health were claimed. Secondly, softer outcomes of increased confidence and increased social networks were claimed for the forecast SROI at the Trust. A description of what was claimed for the study and the research that went into each financial proxy or cost used to value the changes that happened as a result of Budding Builders projects at the Trust are described below.

The DWP study carried out a Cost Benefit Analysis (CBA) of Welfare to Work programmes explains with the exception of health and crime they were able to derive good estimates of willingness to pay (WTP) for most of the economic and social impacts of employment programmes (Fujiwara, 2010). Explaining, “*this is because the majority of the costs and benefits of employment programmes are already in monetary terms, which represent good approximations of WTP*” for example wages (Fujiwara, 2010: 8). Dattani and Trussler (2011) used wages earned by the beneficiaries who gained employment after engaging with Tomorrow's People they used data from Tomorrow's People telephone survey on job titles. They then used the Office of National Statistics (ONS) Annual Survey of Hours and Earnings (ASHE)

that provides the characteristics of earnings for employees within industries, occupations and regions. However, the welfare benefits they would have received if they had remained unemployed were deducted from the wages it was forecast that they would earn. Wright *et al.* (2009: 463) established a monetary value, of an intervention to help people access work in rural communities “*based upon net increases income i.e. client’s wages minus lost welfare benefits and increased taxes*” (Wright *et al.*, 2009: 463).

A direct consequence of higher employment is “*income tax revenues can be expected to be higher than they otherwise would have been*” (Dattani and Trussler, 2011: 18). There are obvious cost savings to the exchequer as a result of previously unemployed people entering employment. The first being an increase in tax revenue, ACEVO (2012: 14) explains, 18 to 24 year olds moving into work “*would contribute a net extra £582 each year to the exchequer through taxes*”. As minimum wage was used in the forecast SROI of the practical project the tax they would pay on minimum wage was claimed for this was calculated at £501.20 (Bridgeman, 2014: 25).

The other benefit of former unemployed people entering employment is a reduction in welfare benefits. The SROI study of Tomorrow’s People estimated reduced welfare payments as a result of the Tomorrow’s People Welfare to Work programmes. This is because an increase in jobs as a result of the activities of Tomorrow’s Peoples would not only increase tax revenues the Exchequer would also benefit from lower benefit payments (Dattani and Trussler, 2011). They calculate employment increases based upon estimating who had secured a job compared to what would have happened in the economy anyway. ACEVO (2012: 14) calculate that 18-24 year old NEETs cost the exchequer £5,663 per year in benefits.

The evidence suggests being in employment improves people’s health. Fujiwara (2010) suggests despite a plethora of evidence of the health benefits of employment it is difficult to actually measure and monetise them. Fujiwara (2010: 36) suggests “*medical service usage rates lend themselves better to monetisation*” and the “*use of medical services can be matched to medical costs to determine monetary value for health outcomes*”. They use a conservative estimate, based on evidence, to assume that as “*people move from employment to unemployment they incur 50 per cent more in medical costs than employed people*” (Fujiwara, 2010: 38). They then use Hojoff’s (2008 in Fujiwara, 2010: 38) estimate of the average annual cost to the NHS of a working age person which was £1,220 in 2008. These figures are used to estimate that when an unemployed person moves into work they save the NHS £610 per annum.

Increasingly it has been acknowledged that soft outcomes for young people such as increased self-confidence can contribute to the achievement of hard outcomes such as securing employment. Softer outcomes such as social and emotional capabilities can be difficult to measure. McNeil *et al* (2012: 7) explain “*self-esteem, resilience and thinking skills, for instance, all underpin young people’s progress but can be hard to assess*”. An initial literature review demonstrated hesitancy to measure soft outcomes in some SROI studies. The SROI of Tomorrows People’s Welfare to Work programmes only focuses on hard outcomes as softer outcomes such as the positive life effects of employment are subjective and difficult to quantify (Dattani and Trussler, 2011). In an SROI of a transport scheme, to help people access employment, Wright *et al* (2009: 463) explain that some outcomes and impacts such as increased self-esteem cannot be easily monetised and therefore “*are often overlooked*”.

Conversely, in the SROI analysis of Jamie Oliver's apprenticeship scheme it was recommended that SROI analysis could be strengthened if soft outcomes were recorded. They continue by recommending a baseline data collection system similar to the outcomes star (Lawlor, 2011). The Trust has existing mechanisms in place to measure change, notably a Progress Web to measure the distance travelled² of beneficiaries as a result of engaging with the Trust. This is a bespoke tool that was developed in-house. The Progress Web consists of a grid where beneficiaries of the Trust measure the progress they make as a result of working with the Trust on a scale of 1 to 8. It was considered that the Progress Webs were analysed to feed into the SROI model at the Trust.

Through consultation with stakeholders on the practical construction projects through semi-structured interviews, telephone interviews and observation it was discovered using their newly learned construction skills to benefit their local community really improves the confidence and self-esteem of young people. The SROI study of the Veterans Contact Point (VCP) used a financial proxy to place a financial value on increased confidence as part of their SROI study. Bates and Yentumi-Orofori, (2013: 1) argue that their research demonstrates significant change to veterans as a result of the VCP and that this change cannot be measured in financial terms of improved finances "*but also in terms of self-esteem and self-confidence*". They use the cost of a confidence course of £1195.00, explaining that this proxy was also used in an unpublished New Economics Foundation (NEF) report 'Coventry Local Enterprise and Growth Initiative'. This financial proxy was taken forward to the SROI study at the Trust.

Beneficiaries also told us they had increased their social networks as a result of participating in the Practical Project. Young people who completed courses at the Trust commented they really valued meeting new people from their local community and making friends on courses. The SROI study of 'Wellbeing Works' Tokarova, (2014) used Janneson's (2010) proxy of £806 to value an increase in social networks. Following an SROI training course Janneson (2010: 48) used participants "*perceived value in relation to total positive value created*" to value increased social networks. The financial proxy of £806 was taken forward to the Trust's SROI study.

Another element that needs to be calculated as part of an SROI analysis is how long outcomes can be claimed for. Pathak and Dattani (2014) explain that two methods are used in the context of business valuations using discounted cash flow model. Firstly, "*to take the economic value of future benefit streams only over an explicit period*" explaining that this can be aligned with business plans or strategic goals. This method assumes the "*same benefit will accrue every year for 20 years*" (Pathak and Dattani, 2014: 95). The second approach "*to project the benefits into infinity using a terminal value*" explaining after five years benefit streams become too uncertain to provide an approximation of value (Pathak and Dattani, 2014: 95). They explain, "*the terminal value in Year 5 divided by (discount rate minus growth rate), where the growth is the anticipated year-on-year growth in benefits*". Pathak and Dattani (2014: 95) suggest that although the second method gives a higher SROI it gives a more robust result when "*forecasting changes in the probability of employment several years hence is impractical and exposes such projections to a variety of uncertainties limiting their validity and credibility to institutional investors*".

² In this context the distance travelled is the progress a beneficiary makes towards a goal

Deadweight refers to the extent of the “*outcome that would have happened even if the activity had not taken place*” (SROI Network, 2012: 56). The deadweight is calculated as a percentage. For example, if an employment programme finds that as a result of its activities 30 per cent of beneficiaries go into employment. However, if the employment statistics went up by fifteen per cent then credit could only be claimed for 15 per cent of beneficiaries. The SROI analysis of St Giles’s Trust Through the Gates scheme used statistics to calculate deadweight. In order to estimate its impact the re-offending rates of clients that they had worked with were compared with national re-offending rates. This was to demonstrate the impact that Through the Gates has “*over and above the national average*” (St Giles Trust, 2009: 10). This was analogous to the method used to calculate the deadweight in employment figures for the SROI model at the Trust. In Birmingham deadweight was considered to be 3.7% as youth unemployment decreased from 13.7% in December 2013 to 10% in August 2014 (Birmingham Council, 2013 and Birmingham Council 2014).

Once the counterfactual has been accounted for the net benefits of the project are divided by the inputs. In the SROI analysis of Construction Youth Trust’s practical project at the Summerfield Community Centre the forecast net benefits totalled £70,328.17. The net benefits were divided by the inputs of the project these were £5,000 donated by the Willmott Dixon Foundation and Willmott Dixon staff time supporting the young people which was valued at £5,800. This resulted in a forecast SROI ratio of £1 :£6.51 indicating if the planned project outcomes are realised there will be £6.51 of wider social value creation for every £1 invested in the project. However, SROI is about the social value a project creates and not just about the SROI ratio and especially without a universal approach the SROI ratio currently needs to be viewed with all the supporting information that led to the headline figure.

CONCLUSIONS

The commencement of the Social Value Act 2012 requires “*public authorities to have regard to economic, social and environmental well-being in connection with public service contracts*” (HMG, 2012). The recent Cabinet Office Review (2015) found that the challenges around defining social value were a barrier to implementing the Social Value Act (Cabinet Office, 2015). However measuring intangibles is not a new phenomenon for the construction industry and there have been challenges measuring intangibles such as the benefits of good design even though design can promote everything from reduced crime to higher productivity (Macmillin, 2005). However, measuring intangibles is not just a problem for the construction industry social value measurement and SROI is a contested field. SROI can be used to measure the triple bottom line of social, economic and environmental benefits. However, SROI is still under development and there are technical challenges implementing the methodology. There is not a universal bank of financial proxies that organisations can use although progress has been made with the Global Value Exchange (no date) an interactive SROI website where users upload proxies. However, we are a long way from a universal language of value for the approach making SROI time consuming and expensive.

The research examined the development of a bespoke SROI methodology at Construction Youth Trust. Focus was placed on the Trust’s practical projects that provide young people with work experience in the heart of their local community. There were two categories of outcomes claimed to forecast the social value that would potentially create project. Firstly, there were employment outcomes based on the Cost

Benefit Analysis framework used to value DWP's Welfare to Work programmes (Fujiwara, 2010). This framework has been applied in other SROI practitioner reports such as the SROI study of Tomorrows People (Dattani and Trussler 2011). Secondly, softer outcomes of increased confidence and increased social networks have been claimed for. The former used in the SROI report of Veterans Contact Point (Bates, and Yentumi-Orofori, 2013) and the latter used in the SROI study of Wellbeing Works (Tokarova, 2014). The SROI ratio for the practical project at the Summerfield Community centre was £1: £6.51 meaning for every £1 invested in the study there was wider value creation of £6.51. This is a powerful indicator of the projects success and illustrates one of the challenges using the SROI approach. The lack of consistency in the process means that the SROI study at the Trust cannot be compared with another SROI study. This effectively means that the whole study needs to be read to understand the value a project creates. There is clearly a need for more research in the SROI methodology and arguably more standardisation of the approach.

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THE IMPACT OF NATIVIST EXCLUSION ON THE MIGRANT LABOURERS IN THE SOUTH AFRICAN CONSTRUCTION INDUSTRY

Nthatsi Khatleli¹

University of the Witwatersrand, Johannesburg, South Africa

South African society has been beset by an endemic problem of xenophobia since its liberation from apartheid in 1994. During apartheid citizens were over-sensitized about their identities through particularistic political prescription of race and ethnic identities. Black South African were oxymoronically referred to as ‘foreign natives’, as they were technically from the Bantustans and not bona fide citizens of the country. When racial segregation was dismantled, only those who could demonstrate a family connection with the colonial/apartheid formation of South African could claim citizenship at liberation. The rest and the deluge of immigrants that followed were regarded as opportunistic claimants to hard fought gains of emancipation. The popular prescriptions founded on indigeneity bolstered the hegemony of xenophobic discourse which reached its zenith during the pogrom of 2008. Although there has never been a repeat of a widespread physical torment of these migrants till recently in March/April 2015, there is a general disquiet among foreigners that the nativist exclusion is bordering on the compromise of the extension of basic humans rights. The majority of these migrants find their way into construction sector of the economy. In this climate of non-abating ethnical tensions, the research is investigating the treatment of foreign construction workers on site. Five case studies which were upwards of \$40 million each were used in Johannesburg where interviews were conducted with foreign workers, construction managers and few local workers as well, for perspective. It was found that job commitment, tenacity, determination and generally better conditions and pay, compared to home countries which have no credible alternatives results in increased loyalty to the employers. Although all the foreigners were regarded to be disciplined productive workforce, their perception of acceptance differed by their country of origin.

Keywords: recruitment, xenophobia, foreign workers, indigeneity.

INTRODUCTION

South Africa has welcomed foreign workers for decades but the ushering of a new dispensation brought unprecedented numbers of foreigners into the land, who entered even the hitherto untouched sectors. The xenophobic sentiments that have developed over the years have affected most workplaces. Unlike other countries which are new to the idea of the globalization, South Africa's labour has always had an international mix. This study seeks to assess how the new negative sentiments towards these arrivals particularly those from beyond the immediate neighbouring countries are treated in the construction.

¹ nthatsi.khatleli@wits.ac.za

The dismantling of Apartheid in 1994 not only ushered in a new dispensation which advocated democracy but opened the floodgates for an unprecedented migration of peoples from the rest of the continent and beyond, most of whom were economic migrants. The concept of the 'push' and 'pull' factors attracting people into South Africa should be understood within a context of specific countries and regions in the continent experiencing one conflict after another (Hussein 2003). The majority of these new arrivals do not have recognized qualifications and some of them are unqualified for highly technical sectors making certain sectors like mining, agriculture and construction the most easily accessible. This happens in a country with progressive migration laws to such an extent that you cannot deny anyone the claim and temporary status of an asylum-seeker, and this is due to a number of precedent setting rulings of the courts, as well as various clauses of the Refugee Act. According to the former Home Affairs minister Pandor (2014) this has led to a situation where economic migrants are abusing the Act in order to have status in South Africa. Unlike many jurisdictions, South Africa grants temporary asylum status to applicants and allows them to work with such a temporary status. The system is bedevilled by its own Act and the human rights jurisprudence prevents introducing changes that detract from the essential core of the human rights character as enshrined in the country's Bill of Rights (Pandor 2014).

LITERATURE REVIEW

A xenophobe is a person who is fearful or contemptuous of that which is foreign, especially strangers or people from different countries and cultures; a phenomenon that can tersely be defined as a deep antipathy to foreigners (OED 2015). When one follows the global literature on globalization, scholarly treatments of xenophobic violence in South Africa also tend to rely on theories of anomie and chaos. This is articulated by Nyamnjoh (2006) when he states *“the accelerated flows of capital, goods, electronic information and migration induced by globalization have exacerbated insecurities and anxieties, bringing about an obsession with citizenship and belonging and the re-actualization of boundaries through xenophobia.”* The basic crux of the arguments is that globalization automatically generates anomie and confusion and that xenophobic violence is a natural reaction to this flux. However, rapid migration, mixing, and culture contact is historically a feature of the sub-continent since the mid-1800s and sometimes in arguably the more extreme forms than today especially when one considers the mfecane, the apartheid era forced removals and other periods of massive intense dislocation (Landau 2010). These events and the recent ones in March/April 2015 have inspired a lot of soul-searching in South Africa as academics seek to explain why multi-culturalism in the much-vaunted Rainbow Nation has become so elusive (Hickel 2014).

Many accounts of the pogroms around the world seem to focus on globalization as a primary driver. Two strands emanate from this argument, one holds that neoliberal policy and structural adjustment undermine livelihoods and spur violent competitions over the ever shrinking scarce resources of housing and jobs. A second strand is preoccupied with identity politics, and posits that the cultural *“flows”* that are characteristic of globalization induce a state of hybridity, flux and moral anomie that triggers the impulse to violently recreate social boundaries (Hickel 2014). In South Africa xenophobia phenomenon is a recent development contextually birthed by the geo-political developments post 1990. Not only did the proxy wars in Africa between the East and West come to an end around this period, but within South Africa itself the newly appointed leaders of the ANC were followed by the citizens of the countries

that gave them shelter during the tumultuous struggle years. These were also joined by peoples from other countries who traditionally had not had their citizens working in South Africa.

History of Labour Migration in South Africa

South African has been a migrant-receiving country for decades, although traditionally the majority of those migrants were from neighbouring countries within the Southern African region. It is important to note that before 1994 the country was also an important destination for (white) immigrants from Europe, who were allowed to have dual citizenship with their countries of origin. Historically the labour migrants were largely concentrated in their largest numbers in the South African mining industry (Pederdy 1999). The precise mix of the source countries varied over time but Mozambique, Lesotho and (until the 1970s) Malawi were the major suppliers. Entry into the country was on a temporary basis on fixed contract and governed by bilateral treaties between South African and the supplier countries. Recruitment was centralized in a single industry-financed monopoly, The Employment Bureau of Africa (TEBA), which managed an extensive network of recruiting offices in supplier states. These migrants were transported home at the end of their contracts to renew; if they became diseased, severely injured or disabled they were sent home (Department of Labour 2007).

Concessions were granted to the commercial agricultural sector and until the 1960s there were arrangements to allow arrested irregular migrants to be employed by commercial farmers (Pederdy 1999). There were regional agreements dating back to the apartheid era but which spilled over into the current era, where the Department of Home Affairs and the Department of Labour allow the recruitment of seasonal agricultural foreign migrant workers (SAMP 2000). Besides these two aforementioned sectors other employers were not permitted to hire foreign labour. However before 1963 there were no restrictions on the movements of migrants from Botswana, Lesotho and Swaziland. Despite these arrangements irregular migrants were repatriated (Pederdy 1999). Irregular migration into South African thus has a long history, although it focused on commercial farming, and to a lesser extent domestic service and construction (Jonathan and Alan 1997). This has created a situation where in most households there is a family member working in South Africa.

South Africa has always had the strong pulling forces as an employment destination. However all black workers local and foreign, were subjected to extreme forms of exploitation under apartheid. Foreign workers were regularly deported or simply left because of apartheid restrictions which made migration very hard. Migration actually peaked in 1951 at just over 600,000 to 320,000 by 1985 (Department of Labour 2007).

The arrival of a new type of immigrant

The international migration is divided into three main types; namely labour mobility, refugee movements and permanent migration (Kok, Gelderblom and van Zyl 2006). It has been noted by others that labour migrants although unskilled, often have considerable entrepreneurial drive towards self-betterment, some complement of skills and some resource in order to finance the trip or trips. Labour migration tends to be cumulative: 'remittances may lead to more migration because they show that migration works, they finance other family members' trips, and they show what the neighbors have to do to "keep up with the Joneses"' (Ellerman 2003:15-16). Remittances from migrants are so significant that they outweigh the international development aid flowing into developing countries.

Refugee movements as with work migrants are reluctant migrants who generally want to return home. When they do, it is often to a developing country, frequently one ravaged by conflict (Nicholson 2002). The last group is that of permanent migration, which is comprised of people who have higher skills as a result of the greater economic return to education in industrial countries. This last group comprise what is normally termed the brain drain (Kok, Gelderblom and zyl 2006).

The immigration statistics in South Africa are very unreliable even by the government's own admission. The highest movement appears to be internal migration since in the new dispensation people are now free to move around from province to province, a scenario that is new in this country. For instance between 2001 and 2007 Gauteng population grew naturally by 74% and only 26% was due to migration with cross-border migration accounting for only 3%. International or cross-border migration is far less numerical, although there are speculations of between 1-8 million. The known statistics are for recognized refugees, asylum seekers, persons with work permits and deportees, although these do not represent migration trends (FMSP 2010). Since the dismantling of apartheid opened a lot of sectors that were a preserve of the locals, the construction sector is one such sector that has been subjected to a deluge of foreign workers. Because of the dire situation they left in their home countries it has been argued that in the construction industry the foreign labourers are more committed and therefore more productive.

RESEARCH METHODOLOGY

This research is mixed method qualitative in that it sought to engage with people and solicited their sentiments about their sentiments towards foreign workers. But since a questionnaire was extensively used it is also quantitative and therefore a mixed method approach. According to Maxwell (2012) to design a qualitative study, one cannot just develop (or borrow) a logical strategy in advance and then implement it faithfully. Qualitative research design, to a much greater extent than quantitative research is an innovative rather than a standardized process, one that involves gleaning back and forth between the different components of the design, assessing their implications for one another. It does not begin from a predetermined starting point or proceed through a fixed sequence of steps, but involves interconnection and interaction among the different design components (Maxwell 2012). So a mixed method offers more than one type of investigative perspective, in that it offers the best of two worlds: the in-depth, contextualised and natural insights of qualitative study bolstered by the predictive power of a quantitative approach. Most pertinently the design must fit not only its use but also its environment. The methods deployed below were the ones it was felt would be the most appropriate for this type of research.

The central question in this study was 'Is the South African construction industry exclusively Hostile Towards Foreign Nationals?' Interviews were conducted with construction managers in five different sites, who are in charge of the work progress, and pertinently with the foreign workers and local workers (10 ~2/site) for perspective. This research is interested in the depth of the data and in appreciating its breath, to attain a proper understanding of the data the researcher has to play an active role in the data collection (Wimmer and Dominick 1997). It was therefore decided that interviewing the people and getting the experiences of the groups from working with each other will give depth and appreciable girth to the enquiry. Describing what an interview is, Frey and Oishi (1995) defined it as a "*purposeful conversation in which one person asks prepared questions (interviewer) and another answers them*

(respondent)” this is done to gain an in-depth information on a particular area to be researched. Open-ended interviews were opted for and they are defined by Nichols (1991) as “*an informal interview, not structured by a standard list of questions. Fieldworkers are free to deal with the topics of interest in any order and to phrase their questions as they think best.*” Open-ended questions allow the interviewer, if they wish, to probe deeper into the initial response of the respondent to gain a more detailed answer to the question (Wimmer and Dominick 1997). The richness of the data can thus be enhanced by this approach. This is very important in a situation where the contracts managers are involved in hiring foreign workers and deal with the problems that could be encountered on a daily basis. The domestic workers also provided insightful input when articulating their sentiments about foreign workers and themes emerged which are discussed below. This is critical as it help us in understanding social phenomena in natural (rather than experimental) settings, giving proper emphasis to the meanings, experiences and views of the participants (Mays and Pope 1995).

A questionnaire was used and 35 respondents were engaged in the five identified sites in Gauteng. The questionnaires were given to foreign workers who were willing to participate although some had reservation talking to people who were outsiders. The same questions were asked to the foreigners, who were seven per site and the intention was to get the widest possible spread of representativity. The questions are shown in figure 2 below. A questionnaire is defined as a formalized set of questions for obtaining information from respondents. The overriding objective is to translate the researcher’s information needs into a set of specific questions that respondents are willing and able to answer. A questionnaire is the main means of collecting quantitative primary data (Malhotra 2011). A questionnaire enables quantitative data to be collected in a standardized way so that the data are internally consistent and coherent for analysis. In all cases the role of the questionnaire is to provide a standardized interview across all subjects. This is so that when the questions are asked or presented, it is always in exactly the same way. To avoid a plethora of different responses that could be saying the same thing put in hundred different ways, questionnaires were thought to be the best tool to provide standard responses that could easily be analysed. The questions dealt with specific challenges foreigners could be facing on site from the information gathered from the media and anecdotal accounts.

The mixed method approach advocated for earlier on was opted for because it was thought both methods together enhance the perspectival clarity of the research problem intensely than either type by itself (Creswell, 2008). The multiple viewpoints accorded by this approach pits the subjectiveness (which provides depth) of qualitative data against the objectiveness (which provides girth) of quantitative approach. This is complementarily beneficial in assisting researchers in properly appreciating the nature and extent of the phenomenon under scrutiny. Interviews elicited common themes from the respondents and the thematic analysis was used to code these themes, after which they were grouped in order to glean any commonalities that might be meaningful. There are two stages to treating themes, the semantic and the latent level (Boytzis, 1998). The semantic looks at the surface meaning of what the data says and does not go beyond what the respondent has actually uttered, without theorizing about the significance of the patterns and their broader meanings and implications (Patton, 1990). On the other hand the latent level goes beyond the semantic content of the data, and starts to identify the underlying ideas, assumptions

and ideologies that are theorized as shaping or informing the semantic content of the data. In this study the contextual political exigencies will not be ignored when latently interpreting the data. Thus for latent thematic analysis, the development of the themes themselves involves interpretative work, and the analysis thus produced goes beyond the descriptive but it already encapsulates theorization. The overall research design is Convergent Parallel Design where quantitative and qualitative data collection and analysis is done separately but the results of both the questionnaires and interviews are compared and related to offer a substantive interpretation. Not only does this approach offer corroboration from different methods but it proffers a more complete understanding from the two databases.

RESULTS AND DISCUSSIONS

The research was taken before the current spate of xenophobic attacks in South Africa as of April/March 2015. We believe the results are not tainted by the heightened negative sentiments towards foreign workers. Interviews were held with the contracts managers in 5 sites and also with local workers for perspective and questionnaires were handed to willing foreign workers. In interviewing the contracts managers and local labourers certain themes emerged as shown in figure 1 below. It was clear that there is no official stance in all the companies to preclude foreigners from employment although managers were in agreement with their employees that there is proclivity to commitment by the foreigners vis-à-vis their local colleagues. A situation which is bolstered by literature when one looks at the dire situations they left in their home countries. The general exclusive sentiments which were tantamount to making the industry a preserve of the locals were voiced more by the locals with managers not demonstrating any stance on this issue. However xenophobic acts were observed even by some contracts managers and their staff in the form of intimidation, name-calling, general disrespect and bullying. This has been observed in the society at large and it is an observed phenomenon especially during periods of heightened ethnic tensions. What was surprising was the general regard of BOLESWA citizens as not technically foreign, a fact which could be attributed to ethnic similarities, historical ties, physiognomic similitudes and their long history of working in South Africa.

The questionnaire yielded the results shown below in figures 2 and 3. The main intention was to assess the treatment of foreign workers by their local peers and by the employer. For the most part it appears that there is some intimidation meted against foreign workers by their local peers. In conducting interviews with them it appears it normally comes from them performing the tasks assigned to them quicker and therefore being used as a benchmark by the employers as how an efficient worker should perform. The intimidation was bad in a few cases that the foreign workers had to change sections or had to resign and find some other work. Apparently there were no major differences in the responses from different sites.

However the discrimination that manifests itself in name calling and the general disrespect is almost non-existent when it comes to employees from BOLESWA (Botswana, Lesotho, Swaziland) countries. The only reason one could find is that ethnically these peoples are related to South Africa and the languages of Sotho (Lesotho), Tswana (Botswana) and Swati (Swaziland) are all spoken in South Africa as one of the nine official languages. Physiognomically these people are not any different from the South Africans and they don't really seem as foreign as the people from other countries. These appear to be the most predominant plausible explanation because the Mozambicans have been working in the country for a long time but they

have never really been accepted. If the construction industry was a new territory for foreigners then the animosity should have been meted against everyone equally. Figure 2 depicts the experiences of foreign workers in different sites. Figure 3 particularly shows the nuances with regards to intimidation that is meted by fellow workers to their peers differentiated by the foreign workers country of origin.

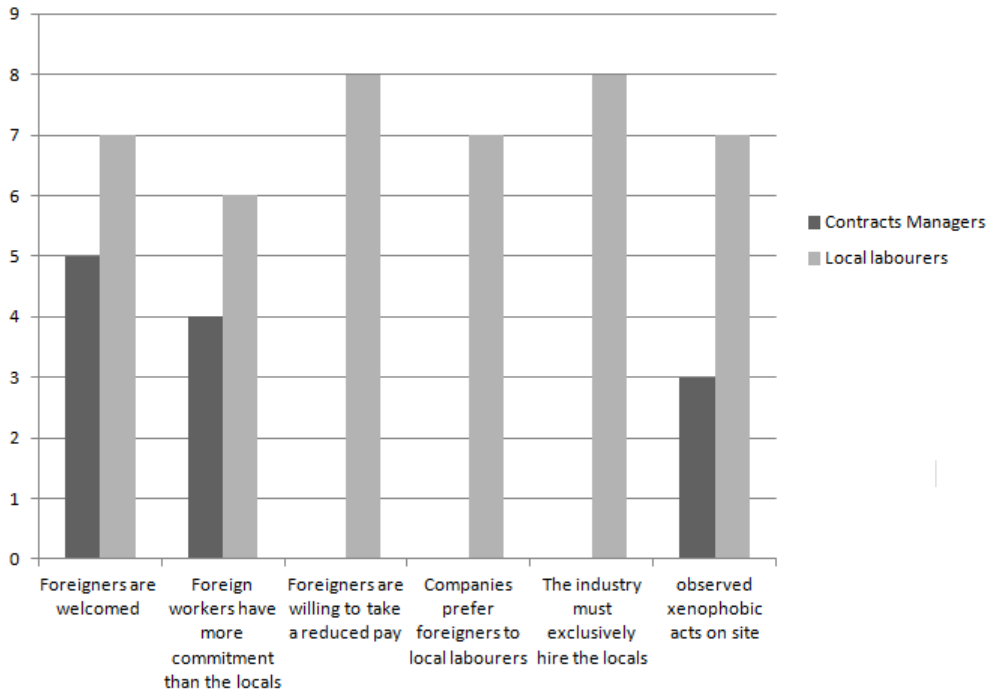


Figure 1: Themes on xenophobia from the interviews

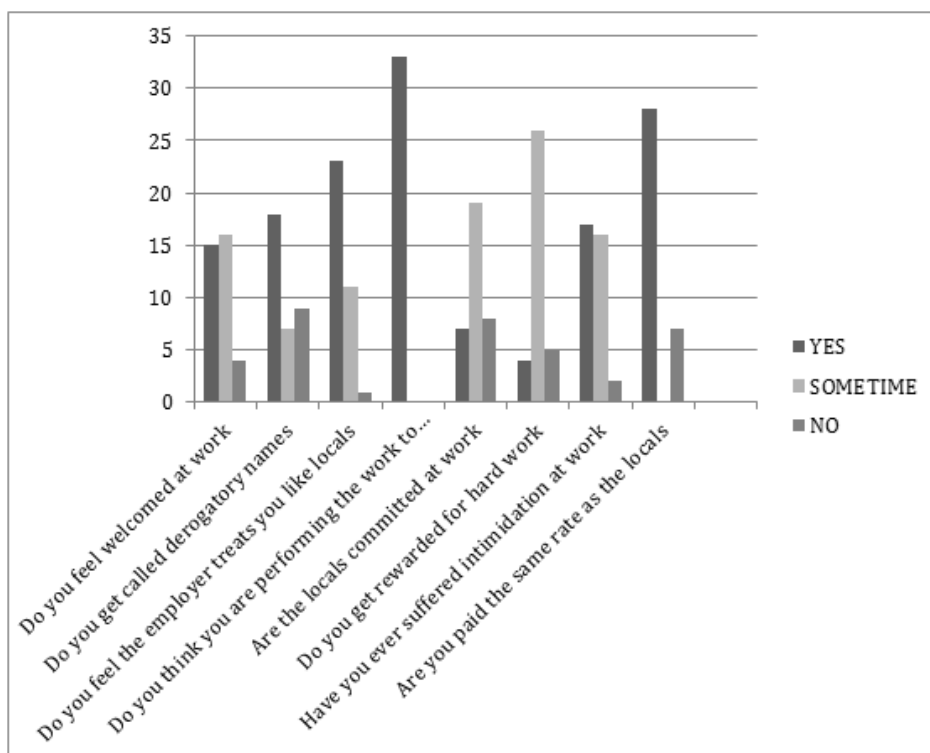


Figure 2: The experiences of foreign workers on site

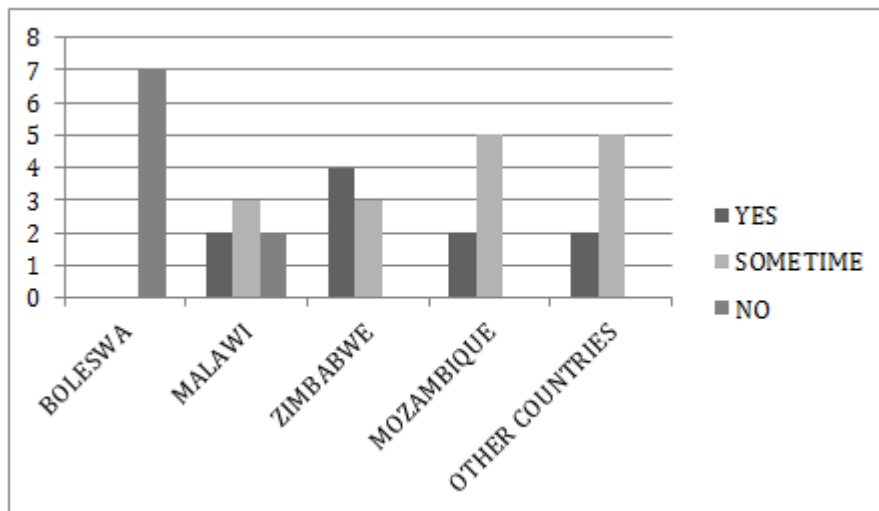


Figure 3: The intimidation experienced by sampled foreign workers on site

The findings from the interviews and the results from the questionnaires appear to offer some corroboration and the findings will be discussed below.

FINDINGS

The construction industry in South Africa fully opened to the foreign workers legally as the same time as the country was opening to the entire world. The only industries that have a history of accepting foreign workers is the mining, agriculture and to a limited extent the domestic services sector. The influx of unskilled migrants found an easy access to the construction sector. Their commitment was embraced and accepted by employers. The local workers generally believe the foreign workers invite their compatriots to the exclusion of the locals once they are in a position of authority to do so. This fuels the accusation of job snitching by foreigners. There were also accusations of accepting lower wages although this could not be proved on the sites visited. Although there is no proof of overwhelming preference to the exclusion of the locals, the preference was perceived as dislodgement from sectors traditionally regarded as a preserve for the unskilled local labourers. This perception and the demonstrable aptitude for productive task execution, has fuelled animosity on the construction sites to such an extent that the intimidation has in some occasions led to foreign workers changing jobs in extreme cases. Foreigners however many they are on a site, as long as they are from BOLESWA countries which have a strong ethnic relation to the South Africans they are treated like locals without any abuse and prejudice. Hence the xenophobia on sites is ethnically nuanced. This happens despite the fact that peoples from most SADC countries in general, have worked in South African mines for over a century.

CONCLUSIONS

Although South Africa has been welcoming foreign workers for decades this was only concentrated on a few sectors namely, mining, agriculture and domestic service. The arrival of new migrants post-1994 who have come to the land to seek better livelihoods have created a new significant foreign element in the workforce. Although there are many foreigners in South Africa, prejudice was found to be rife and nuanced and the following conclusions were made:

7. Foreigner workers treatment is ethnically nuanced. BOLESWA foreign workers who are ethnically similar to indigenous South Africans are treated like the locals by their peers.
8. The otherness of the foreign workers is predominant at the coalface but there is no systematic official sanctioned ill-treatment by companies.
9. The general negative sentiments toward foreign workers, which are manifested in prejudice and intimidation are not officially sanctioned but are rife at the grassroots level.
10. The dire politically conditions in the home countries of foreign workers result in workers who value their work and demonstrate a comparatively better commitment which has endeared them to their employers.
11. Because of the official stance of the companies which is not exclusive, the xenophobic tendencies of the staff does impact the new foreigners seeking to join the industry, and the foreign talent is not lost.

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USE OF ADVANCED AND GREEN CONSTRUCTION MATERIALS BY SMALL AND MEDIUM-SIZED ENTERPRISES

David Thorpe¹ and Christopher Wright²

¹*Faculty of Engineering and Surveying, University of Southern Queensland, Queensland, Australia*

²*Opus International Consultants, Melbourne, Australia*

The use of advanced and green materials by the construction industry can significantly improve sustainability by reducing demand on scarce resources, reducing greenhouse gas emissions, improving safety, facilitating resilience of structures and encouraging the use of modern construction practices. Examples of such material include laminated veneer lumber, glulam, rammed earth, high strength concrete, lightweight concrete and adobe brick. To evaluate the use of such materials, an exploratory survey was conducted on-line in Australia and New Zealand into their use by small and medium enterprises (SMEs) that were undertaking either design or construction. The purpose of this survey was to better understand the use of such materials by the selected firms, understand why they were used or not used, and assess their likelihood of use in the future. Thirty firms responded to the survey. Each firm was asked to respond in detail to the use of five advanced and green materials, selected from a total number of sixteen. The extent to which these materials were used varied by individual firms and their role in the industry. It was found that there were seven leading issues (or factors) with respect to the use of such materials. The range of factors tended to depend on whether or not the firm had used the selected material. Experience appeared to be the leading issue restricting the uptake of individual materials. Other factors included cost of material and the availability of standards or codes of practice. While it is recognised that further work is required to validate the results of this research and extend it beyond Australia and New Zealand, this survey has given good insight into the use of these materials by SME firms in the construction industry.

Keywords: green buildings, material usage, small and medium enterprises, sustainability, technology transfer.

INTRODUCTION

Advanced and green materials in the construction industry can significantly improve sustainability by reducing demand on scarce resources, reducing greenhouse gas emissions, improving safety, facilitating sustainability and resilience of structures and encouraging the use of modern construction practices. While there have been a number of applications of these materials, their uptake at a more general level in civil engineering and building projects, and particular the small and medium enterprise (SME) building and construction sector, has not always been as rapid as it might be.

A number of such materials have considerable promise in terms of innovation in engineering design, construction and asset management. Polymer composites, for

¹ thorped@usq.edu.au

example, are used in a number of construction applications, such as non-critical structures. There are also a number of applications of other construction materials, such as advanced concrete products and timber based composite materials like glulam.

The SME construction sector can be quite innovative, such as with the adoption of proven products and improved processes (Thorpe *et al.* 2009). There are, however, factors that can impact on the adoption of new materials by firms in this sector, such as price, which is driven by the competitive tendering process, and was found to be the main factor in a study on the adoption of pozzolans as substitutes for cement in Wales (O'Farrell and Miller 2003).

To better understand the adoption process with respect to advanced and green materials, exploratory research was undertaken to evaluate issues for SMEs in the use of advanced and green engineering materials (AGEMs), which require considerable investment and resources in research, design and innovation to develop. SMEs play a large part in the construction market and therefore their adoption of new materials can be crucial to the success of advanced and green engineering material products.

The objectives of this research have been to:

- undertake a survey of SMEs to identify their perceived issues in the use of AGEMs
- evaluate the issues for SMEs in the use of AGEMs
- undertake exploratory research to support further studies into the issues with the use of AGEM for material manufacturers and the construction industry, and particularly its SME firms.

The main terms, and the issues (or factors) in the use of advanced and green materials in the construction industry, are discussed in more detail below.

ISSUES IN THE USE OF ADVANCED AND GREEN MATERIALS

Description of Advanced and Green Materials

Advanced materials are an improvement on conventional materials. They are developed to enhance strengths, or mitigate weaknesses of conventional materials. Polymer composites, advanced concrete products and glulam have previously been listed. Other examples of such materials include post-tensioned timber, which combines timber's flexibility, aesthetic and environmentally friendly properties, with the ductile properties of steel to improve the ductility and strength of timber (Symons 2014); and ductile self-compacting concrete (DSCC), which minimises the need for skilled labour as levelling and compaction occurs under self-weight (Nuruddin *et al.* 2014). A New Zealand company is manufacturing an advanced heavy timber material, cross-laminated timber (CLT), which has strong demand in Europe and elsewhere (Symons 2014).

The definition of green materials is contested and seldom completely understood, with greenwashing leading to reports that Americans believe only 12% of products that claim to be green actually are, through to consumers tending to rank equally environmentally friendly products differently due to the centrality of the green component (Gershoff and Frels 2015). This research used the definition that green (or sustainable) materials can provide a more energy efficient alternative to conventional materials. They may be classified into one or more of six categories such as green process, improved sustainability, recycled content, recyclability, low toxicity and biodegradability (RSMMeans 2002: 232-234). The nature of green can be challenging for practitioners due to the wide variance of materials conforming in one form or

another, to one or more categories, which adds an extra layer of complexity to the evaluation of alternatives.

Use of Advanced and Green Materials by SMEs

Small and medium-sized enterprises (SME), which are distinguished from larger firms by the number of staff employed and legal forms of business, comprise a significant number of the business enterprises in modern countries. In New Zealand, for example, SMEs firms have up to 49 employees, with firms of up to 19 employees accounting for 97% of enterprises (Ministry of Business, Innovation and Employment, 2014). SME firms in Australia may have up to 199 employees, and comprise over 99% of actively trading businesses (SME Association of Australia 2015). Their legal forms of business can include sole proprietorship, partnership, or corporation, each of which has a different structure, may be assessed for taxation differently, and may have different approaches to risk management.

While advanced and green materials are developed to extend the boundaries of conventional materials and help in the provision of an environment that can be enjoyed by future generations, the research, design and innovation involved in developing them can take sizable resources and investment, and therefore they can be relatively costly compared with traditional materials. Their perception can also impact adoption, particularly by the SME sector, which because of the smaller size of firms, has less capacity to take risks than better financed larger firms.

Factors related to materials include material properties, and the perception, environmental impact and selection of materials available. In addition, the use of the term “*green*” may lead to perceptions of something that is low-technology, uncontrolled and unprofitable to SMEs. Some manufacturers may be reluctant to advertise the use of green processes for fear of prejudice (Spiegel and Meadows 1999).

There may also be relatively few standards and guidelines for advanced and green materials, with those that are available being performance rather than prescriptive (Spiegel and Meadows 1999). The lack of standards has been highlighted more recently by the Queensland Department of Transport and Main Roads in the case of engineered fibre composites, in which it was observed that there was a lack of an Australian standard for that product. Fragmentation and the use of Intellectual Property as a tool to closely guard information, but also limit transparency surrounding manufacturing, can limit the openness of information published in papers. Ultimately, such a lack of standards poses a professional indemnity risk for designers (Pritchard 2014).

Green materials may also suffer from requirements to both use the standards of the conventional materials they are replacing and meet the requirements of sustainable design standards such as BREEAM (BRE Global Limited 2014) to demonstrate the sustainability aspects of a material. Thus while construction using green materials is required to be built and managed to a budget and provide economic benefit, it should also implement sustainable development requirements (Brundtland 1987) by maintaining the balance between the economic, social and environmental aspects of sustainability.

Overall, while there are likely to be a number of positive features for the use by the SME construction sector of advanced and green materials, there are also a number of barriers to their adoption by this sector, including perception of the materials and their

use, and both design and construction risks associated with the requirement for more standards. The next section discusses additional factors that may impact on the use of such materials by the SME construction sector.

INVESTIGATION OF THE MATERIAL USAGE DECISION

Factors affecting the decision by SMEs to adopt advanced and green materials

The adoption by an organisation of an advanced or green material is an innovative step. An innovation may be defined as an idea, practice, or object that is perceived as new (Rogers 2003: 12). In the decision to adopt an innovation, the potential user of the innovation gains knowledge of the innovation, forms an attitude about it, makes a decision whether to accept or reject it, implements the new idea, and confirms the decision (Rogers, 2003: 168-170). There are rewards for early adopters of an innovation, and also negative risks, such as potential financial loss. This situation is particularly relevant for SMEs, which tend to be more exposed to such risks as they are generally younger (Abdullah and Manan 2011) than larger mature firms and are likely to be experiencing higher growth than them, particularly in an active industry like construction, in which there tends to be a strong demand for materials. Such materials are required to be profitable to the firm, in order that the firm can pay interest on funds borrowed or pay dividends to equity investors, and thus grow.

In addition to perception, the limited availability of standards and the matters associated with growth, a number of other factors (or issues) have been identified, through literature or hypothesized by the authors, which have the potential to impact on the use of advanced and green materials by the SME sector. A discussion of these additional factors is below.

Experience

The construction industry tends to rely on previous experiences to guide future decisions. As SMEs have less access to expert opinion than larger organisations, advanced and green materials carry more risk to SMEs with less experience. This risk increases the risk premium used in their evaluation (Brooks 2010).

Identification and Evaluation of Materials

The identification of the most suitable materials for a particular application may be quite complex and costly as a result of the number of alternatives available. Evaluation methods will include financial assessment and may also include other considerations such as ease of use of the material, its acceptance by clients, its availability and ethical considerations, including the evaluation of externalities, which refer to situations when the effect of production or consumption of goods and services imposes costs or benefits on others which are not reflected in the prices charged for the goods and services being provided (OECD 2003). They include positive externalities, such as improved air quality from using green material; and negative externalities, such as greenhouse gases created in the production of Portland cement. Externalities can be difficult to evaluate and quantify.

Material Cost

SMEs are likely to have less access to capital than larger organisations, thus making them quite sensitive to material cost. Advanced and green materials tend to be more expensive by face value. For example, conventional 30 MPa concrete tends to cost less than 30 MPa lightweight concrete (Simons 2012). This premium in the cost of such materials covers externalities, or compensates for research and development or specialist knowledge and labour required. Externalities can include improved future sustainability. For example, in timber products, there may be a premium paid for

maintaining forests through planting and other resource management (Mankiw 2009). Other sources of cost include investigation and evaluation of new materials; and the difficulty of evaluating future benefits of new materials, which can make it challenging to justify their use given their increased cost.

Inventory management

Inventory management is closely linked with working capital and the management of current assets. Firms require working capital, which is the net of current assets and liabilities, to operate. A lack of working capital will lead to insolvency. Thus maintaining positive working capital is an issue to firms of any size (Brooks 2010).

Availability and properties of materials

Availability of materials is also a likely factor in the decision to adopt advanced and green materials. It varies with the material. For example, concrete is very widely used, and timber and wood are renewable resources when managed sustainably. The availability of earthen materials, for example, would be expected to be locality dependent. The properties of materials, and knowledge of these properties, can also impact on the material usage decision. For example, research on earthen materials tends to lack depth and consistency compared with research of other engineering and construction materials.

Materials investigated for this research

While there is a large selection of advanced and green materials available, it was decided to limit those used for this research to a representative group of such materials primarily used in the building structure. The materials used for this research were:

- Advanced concrete materials - ductile self-compacting concrete (Naik *et al.* 2008); high strength concrete; lightweight concrete; fibre reinforced concrete (Sivakumar and Santhanam 2007); cement replacement materials, such as pozzolans and geopolymers.
- Earthen Materials (Miccoli, Muller, and Fontana 2014) - adobe brick, rammed earth; cob (a mixture of earth, water and plant materials).
- Timber - glued-laminated lumber (Glulam); laminated timber lumber (LVL); cross-laminated timber (CLT); hybrid timber with post-tensioning reinforcing (Symons 2014); glued-laminated bamboo (Glulam) (Xiao *et al.* 2014); hybrid timber with fibre reinforced polymers.
- Other - green roof and pervious concrete.

Each of these materials has quite different properties and uses.

RESEARCH DESIGN AND IMPLEMENTATION

In order to further investigate the use of advanced and green materials in SME firms in the construction industry in Australia and New Zealand, a survey was conducted in mid-2014. This survey was approved by the Human Research Ethics Committee of the University, and is discussed in further detail below.

Survey questions

The survey questions were formulated to: collect generic firm details; evaluate issues that the firm had with advanced and green materials; identify such materials previously used and unused by the firms; and assess whether their use would continue (for used advanced and green materials, or commence (for unused materials), with or without perceived issues being addressed. Participants were asked to select materials from the list of 16 materials listed above, or could nominate other materials.

The questions were split into four sections, as follows:

12. Business profile - type of firm, staff numbers, areas of the construction industry and regions in which the firm operates, use of AGEMs.
13. The three most common AGEMs used by the firm, including use of the material, main issues in its use, whether firm will continue using it.
14. Two AGEMs not used by the firm (selected by the firm) - issues preventing use (selected from a list), questions about material and possible future use.
15. General issues with AGEMs - issues (selected from a list) ranked on a five point Likert (strongly disagree to strongly agree) scale, how firms identifies potential materials for use, how firms evaluates alternate materials.

The issues (or factors) to which responses were requested at a general level were standards or codes, experience, identification of alternative materials, evaluation methods, inventory management, cost of material, material properties, perception and growth of business. For individual materials not used by the firm, the factors were standards or codes, experience, evaluation methods, inventory management, availability, cost of material, material properties and perception. Respondents could add additional materials and issues to those asked. While responses to most questions were specific, open questions of how the firm identified potential materials for use and evaluated alternate materials sought more detailed answers.

Selection of firms

A number of SME firms in the construction industry in the three disciplines of architecture, engineering and construction in Australia and New Zealand were invited to participate in the survey. The list of participants invited was collected from the 16 regions (up to 10 firms from each region per discipline) of New Zealand, and 6 states (up to 20 firms from each state per discipline) of Australia. The firms invited to participate were identified from the Yellow Pages telephone business directories of New Zealand and Australia. This process resulted in an email list of 749 firms.

Administration of the survey

The survey was administered using an online data collection tool, using email, Facebook posts and a web link. An initial email containing the survey was followed up, if there was no response initially, with a second email showing the link to the Facebook page. In the third week of the survey, a further email was sent to firms yet to respond with a web link.

There were 30 firms that responded to the survey. While this number was not high, it did permit analysis of the sample of firms that responded to the survey, but was less satisfactory for analysis of results by discipline or country (19 responses were received from New Zealand and 11 responses from Australia), or for detailed trends to be examined for each material. The relatively high proportion of responses from architects (50 per cent of responses, compared with 20 per cent of engineers and 30 per cent of contractors) could potentially introduce bias into the sample. The breakdown of responses by discipline and country is shown in Table 1.

Table 1: Breakdown of number of firms responding by discipline and country

Country	Architect	Engineer	Contractor	Total
New Zealand	11	2	6	19
Australia	4	4	3	11
TOTAL	15	6	9	30

While 30 responses is not ideal and cannot be claimed to represent an industry of many thousands of firms, it is contended that it can provide some indication of how

results of the survey can be perceived by industry. The basis for this statement is that according to Hamburg (1970), the sample size n for a given estimation of the mean is given by the formula $(z^2 \cdot \text{variance} / e^2)$, where “ z ” is the number of standard deviations from the mean for a desired confidence level and e is the magnitude of the error. Transforming this formula to calculate “ e ” given “ n ” shows that a sample size of 30 would, for a variance of 1.0 (considered on the high side for most 1 to 5 Likert Scale results) and a z value of 2.0 (about 95 per cent of a normal distribution), result in an error in the mean of ± 0.365 from the point of view of the overall population, which is well within the limits of one gradation in a five point Likert Scale. The use of a more qualitative interpretation of most responses to the survey is also considered to aid its wider applicability.

MAIN FINDINGS

Issues in the use of advanced and green materials

The majority of firms approached in this exploratory review (90 per cent) indicated that they used advanced or green materials. Their main use was occasionally (50 per cent of firms). The inclusion of focus groups and in-depth interviews in further research will help to determine whether a bias towards firms that have previously used advanced and green construction materials responded to the survey was present.

With respect to issues (or factors) in the use of these materials at a general level, seven factors out of the nine to which responses were requested were considered significant. They received a mean ranking from the survey of more than three (3) on a 1 to 5 Likert scale, and were experience, perception, cost of material, standards or codes, evaluation methods, identification of alternatives and material properties. Growth of business and inventory management were considerably less significant in the decision by firms to use these materials.

The main ways in which firms identified potential materials for use were research, reading (for example, trade literature), client and peer discussions, and investigation of design and performance of the material. In evaluating alternative materials, there was a stronger focus on in-depth research, assessing technical specifications and testing.

Materials commonly adopted by SMEs

There were six advanced and green materials commonly adopted by at least 10 per cent of the SME respondents. They were:

- Laminated veneer lumber (LVL), used in roofs, floors, walls and inbuilt furniture. The main factors in use were cost of material, material properties and availability.
- Glulam, used in roof, floors and walls. The main factors in its use were cost of material, availability and evaluation methods.
- Rammed earth, used in walls and retaining walls. The main factors in its use were cost of material, experience, perception and material properties.
- High strength concrete, used in floors, road pavement and foundations. The factors in its use were cost of material and experience.
- Lightweight concrete, used in walls and floors. The factors in its use were cost of material, experience, availability and material properties and availability.
- Adobe brick, used in walls. The main factors in its use were material properties, experience and evaluation methods.

Overall, the main factors in the use of these materials were cost of material, material properties, experience and availability. Evaluation methods and standards and codes

were also listed as factors by respondents. With the exceptions of high strength concrete and adobe brick (both of which are expected to continue to be used by the majority of respondents), all materials are expected to be used in the future.

Materials not commonly adopted by SMEs

Six advanced and green materials were commonly not adopted by SMEs. They were:

- Post-tensioned timber
- Cement replacement materials
- Cob
- Cross laminated timber (CLT)
- Ductile self-compacting concrete (DSCC)
- Rammed earth.

The main issues in the non-use of these materials were experience, standards or codes, availability, evaluation methods and cost of material. High strength concrete was likely to be used in the future by all respondents if the issues were addressed. There was doubt about the future use of cob, ductile self-compacting concrete and rammed earth.

DISCUSSION AND CONCLUSION

Of the 30 firms responding to the survey, 90 per cent had used advanced or green materials. There were seven main factors, which are a combination of organisational factors and factors specific to each material that affected the decision whether to use these materials.

It was found that the main four factors relating to AGEMs commonly used by the SMEs in the sample of 30 were cost of materials, material properties, availability and experience. For AGEMs not commonly adopted by SMEs, the main factors were experience, standards or codes, availability, evaluation methods and cost of material.

Experience and cost of materials were common to all three sets of factors, and can therefore be considered significant in any decision with respect to the firms in the decision whether to use a particular advanced or green material. Material properties were significant at the general level and for materials commonly adopted by SMEs. Standards and codes were significant at both the general level and for AGEMs not previously adopted by SMEs. It is therefore considered that properties of materials, and the availability of standards and codes, both of which may be considered related to the material, are important considerations in the new material selection process.

It follows that the primary factors in any decision by the SMEs surveyed to use an advanced or green material were experience and matters related to the material itself. These findings tend to be supported by the innovation decision process discussed by Rogers (2003) and other literature. For example, the study by Thorpe *et al.* (2009) into innovation in small residential builders found that most innovations tended to be those developed or researched by the firms themselves. As discussed previously, Pritchard (2014) noted that a lack of standards and other factors related to materials and the construction industry impeded the use of advanced materials like fibre composites in the road industry, and also imposed a risk on their use in design.

Of the materials that the respondents were asked to consider, the most commonly used materials laminated veneer lumber, glulam, lightweight and high strength concrete, rammed earth and adobe brick. These materials had different applications in the construction industry. Only post-tensioned timber, cement replacement materials, cob,

ductile self-compacting concrete, and timber with fibre reinforced polymer were not used. Most of these materials would be used if current issues were addressed. Therefore, there was reasonable usage among the respondents of these materials. The range of factors in their evaluation by the firms depended on whether the material had been used before, with tangible factors (such as cost of material) predominating over intangible factors (such as experience) for materials that had been used by firms. Intangible factors tended to be dominant for materials that had not been used by them. Price was an issue noted in the study by the previously cited study O'Farrell and Miller (2003) into the use of pozzolans in Wales.

The main materials used tended to be fairly well-known to the industry. This consideration, along with the strong focus on experience and factors related to particular materials, may reflect the lower risk taking approach of SME firms compared with larger and better resourced firms, which would result in their being later adopters of product innovations. This caution is underscored by the verbal responses to the identification and evaluation of potential new materials, which indicated a cautious approach to their use. One possible option with respect to encouraging more use of such materials by SME firms could be improving their awareness and understanding of them through dissemination (for example, through industry organisations and education).

Because of the small sample size of respondents to this research, its results can be viewed as indicative only of the use of advanced and green materials in SME firms in the construction industry. A logical extension to this research is to validate it, possibly through using one or more focus groups, a Delphi survey, in-depth interviews, or similar approaches. Doing so would present the research questions to a different group, and may also overcome bias towards architectural firms in the sample. It could also address another potential source of bias in the survey, which is that firms with little or no previous use in these materials may choose to ignore the survey. Other improvements to future research might include the addition of other materials, such as advanced plastics and metals, in-depth elicitation of reasons by firms for using selected materials, and extension of this research beyond Australia and New Zealand.

Overall, this research has shown that, within the group of firms undertaking this survey in the SME construction sector in Australia and New Zealand, there is good use of particular advanced and green building materials, but less use of others. As AGEMs have the potential to contribute substantially to sustainable construction practices, it is desirable that their use be encouraged. Steps to improve their use that have been provisionally identified in this research include the development of detailed standards and codes, an improved pricing structure, and developing knowledge and use of them through knowledge dissemination and the provision of opportunities for firms to gain experience with them.

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INVESTIGATING THE EXTENT TO WHICH WASTE MANAGEMENT LEGISLATION AFFECTS WASTE MANAGEMENT PRACTICES WITHIN THE UK CONSTRUCTION INDUSTRY

Solomon Adjei¹, Nii Ankrah, Issaka Ndekugri and David Searle

Department of Built environment, Faculty of Science and Engineering, University of Wolverhampton, Wolverhampton, WV1 1LY, UK

Studies on construction, demolition and excavation (CD&E) waste management (WM) suggest that among many success factors for ensuring sustainable management of waste, government legislation is the most critical. In the UK, there has been different legislation targeting the management of waste of which CD&E waste is a priority stream. To determine the criticality of waste legislation in the management of CD&E waste, this research investigated the drivers that dictate the WM strategies of construction firms. The study was conducted through a multiple case study approach using four construction firms who received awards for their environmental management and sustainability practices on their construction sites in 2013. Data was collected through interviews with the sustainability and environmental managers of the companies who have the overall responsibility for WM strategy in their firms and review of the environmental and waste policy documents of these firms. The results suggest that, although government legislation plays a role in the WM strategy of these companies, legislation is not the most critical driver for WM practices as firms pursue WM for other reasons such as, cost reduction, company sustainability agenda, client demands, company image, and industry benchmarking. The research concludes that, to ensure sustainable management of CD&E waste, more attention should be directed at these other reasons for which firms manage waste. For legislators, proactive enforcement approaches which can detect and prosecute for non-compliance will make legislation a key driver. Legislation should also be tied to financial incentives and targets should include the client whose demands act as a key driver. For clients to make more inputs, their demands can also be tied to cost implications as this is the number one driver for contractors. For contractors, sustainable WM should be pursued as it makes good economic sense through cost reduction on projects and increase in the possibility of winning work from environmentally aware clients.

Keywords: construction and demolition waste, drivers, waste legislation, waste management practice, waste management strategy.

INTRODUCTION

Studies on environmental management (EM) suggest there is the need to control the pollution of the environment and the management of resources to ensure sustainable development is achieved (Barrow, 2004, p.12; Mohammad, 2013). A key aspect of EM, which targets decoupling environmental pollution from the level of development, is the management of waste. In this regard, the construction industry is considered key because of the environmental and social impacts that occur at each stage of the

¹ solomon.adjei@wlv.ac.uk

construction ‘lifecycle’; from the extraction of raw materials, through processing, construction, demolition and recycling, to final disposal (Craighill and Powell, 1996). Construction activities such as excavation, building and civil works, site clearance, demolition, road works, and building renovation are the main causes of waste generation in the construction industry (Tam, 2008). The contribution of construction, demolition and excavation (CD&E) waste to the total waste stream in any developed economy is between 10 and 40% (Lu and Yuan, 2011). The concern for these high levels of CD&E waste is multiple folds: running up a large amount of land resources for waste landfilling (Jaillon *et al.*, 2009); harming the surroundings by hazardous pollution; wasting natural resources (Yuan and Shen, 2010) and increase in the cost of construction projects (Hao *et al.*, 2008). For these reasons, CD&E waste management (WM) has become an established discipline worldwide (Lu and Yuan, 2011).

One of the major accusations levelled against the construction industry is the excessive consumption of global resources (Curwell and Cooper, 1998; Ding, 2008). This accusation, puts increasing pressure on the industry to find ways of reducing the over reliance on natural resources. The promotion of EM, coupled with the mission of sustainable development has resulted in pressure demanding the adoption of appropriate methods to improve environmental performance of the construction industry (Udawatta *et al.*, 2015). The Sustainable development paradigm has been one of the driving forces in shaping waste legislation and policy since the 1980s and has led to WM approaches embracing the three dimensions of sustainability; social, economic and environment (Strange, 2002; Yuan, 2012).

CONSTRUCTION WASTE MANAGEMENT AND LEGISLATION

Research on the subject of CD&E WM, report that WM legislation is one of the most critical factors to ensure the negative effects of waste on the environment are controlled (Osmani *et al.*, 2008; Jallion and Poon, 2008; Wang *et al.*, 2010; Yuan, 2013). The EU since 1992 has regarded CD&E waste as a priority waste stream leading to upsurge in WM legislation and increased pressure on the industry to manage waste. In the UK, waste legislation is derived from the EU regulatory framework (Burmer and Burch, 2005; Jordan, 2006). The overarching legislative framework for the WM in the EU is the EU Waste Framework Directive (WFD) (Directive 2006/12/EC on waste) which sets the obligations for member states on the collection, transport, recovery and disposal of waste. The amended Waste Framework Directive 2008 (Directive 2008/98/EC), sets the obligation for member states to take appropriate measures to encourage: the prevention or reduction of waste production and its harmfulness; and the recovery of waste by means of recycling, re-use or reclamation or any other processes with a view to extracting secondary raw materials, or the use of waste as a source of energy (DEFRA, 2012). Other Directives which affect CD&E WM are the Landfill Directive (1999/31/EC) and the Integrated Pollution Prevention and Control Directive (IPPC) (2008/1/EC). The aims of EU waste legislation are promoted by the EU WM principles (prevention principle, precautionary principle, polluter pays responsibility, and principles of proximity and self-sufficiency) and the EU waste hierarchy (Strange 2002).

The legislative framework for CD&E WM is shaped by sustainable development concerns such as; the need to reduce the level of pollution of the environment, the need to reduce the over reliance on and depletion of natural resources, and running out of space for waste landfilling. The EU waste legislation and policy set the goal to ensure 70% of all CD&E waste is reused, recycled or recovered by 2020. Notable

regulations in the UK transposing EU Directives are the Wastes (England and Wales) Regulations 2012, Environmental Permitting (England and Wales) Amendment Regulation (EPR) 2012 and the Hazardous Waste (England and Wales) Regulations 2005. The most recent CD&E WM specific regulation in the UK was the Site Waste Management Plans Regulations (SWMP) 2008 which sought to promote sustainable management of CD&E WM but this was repealed in December 2013 as part of the DEFRA red tape legislation challenge.

Waste regulations impose obligations on construction firms who devote resources to meet regulatory requirements. To sceptics, WM regulations is a major burden on industry and business (Jordan, 2006; Baldwin *et al.*, 2011), while supporters suggest regulations promise economic advantages and a green light to innovation (del Río Merino, *et al.*, 2010; Baldwin *et al.*, 2011).

The criticality of government legislation in driving sustainable WM is the ability to cause a behavioural change in the industry (Wang *et al.*, 2010). Studies by Jaillon and Poon (2008) and Karavezyris (2007) suggest that government plays a crucial role in promoting CD&E WM practices by enforcing policies for the whole industry. For a WM system to be sustainable, it needs to be environmentally effective, economically affordable and socially acceptable (Ye *et al.*, 2012; Yuan, 2012). This suggests that the drivers for sustainable WM within the construction industry may go beyond legislative demands to encompass social concerns and economic incentives. To determine the extent to which government legislation affects WM practices within the industry, this research investigates the drivers for WM within the UK construction.

This research is part of a PhD research at the Faculty of Science and Engineering within the University of Wolverhampton which seeks to investigate WM practices of construction firms in the UK.

METHODOLOGY

This paper reports results from a PhD research which uses a multiple embedded case study approach (Yin, 2014). Four companies were selected from a list of award winners from different awards schemes within the UK construction industry in 2013. The award winners selected for this research were from categories relating to sustainability and environmental management. Data on the drivers for WM was collected through interviews with sustainability and environmental managers or directors in the companies who have responsibility for WM at the corporate level of the companies. Documentary evidence on corporate level WM was also reviewed. The QSR qualitative data analysis software Nvivo10 was used as the main tool to help in data analysis process through coding (Miles and Huberman, 1994) of the interview transcripts and documents imported into the software. Through description, analysis and interpretation, stages of qualitative data analysis (Wolcott, 1994), the files imported into NVivo were coded based on three main coding styles, open, axial and selective coding. To ensure an in-depth analysis of the data, the coding process began with micro analysis of the interview transcripts and documents through open coding. The codes generated were grouped together through axial coding to form themes and subthemes which served as the main basis for presenting and discussion of the results.

ANALYSIS AND DISCUSSION OF RESULTS

The results of the analysis of the data indicate that, though the drivers for WM are not exactly the same within the four companies, they can be grouped under nine (9) common categories (themes). These are: benchmarking; client demands; company

vision/agenda; economic concerns; environmental concerns; legislation on waste; reputation and image; resource demands for WM; standards rating and support systems. (This is shown in the NVivo output below)

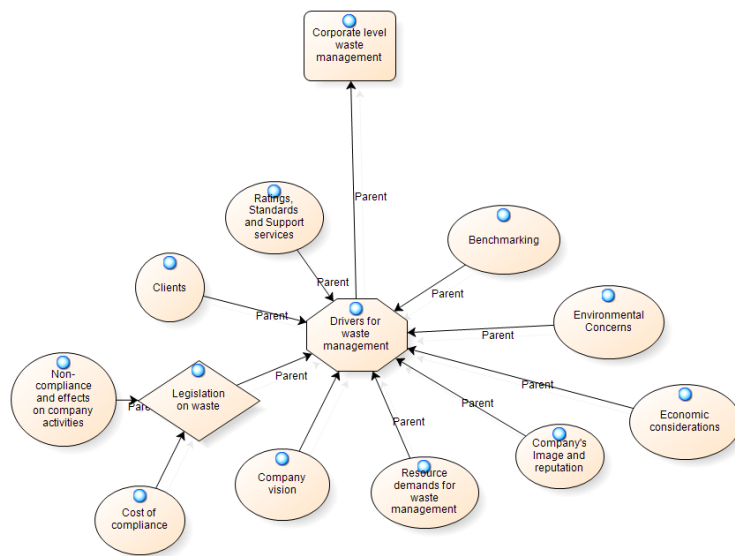


Figure 4 Drivers for waste management

Figure 1 above shows an NVivo output of the drivers of WM from all the companies involved in this research. The extent to which these factors drive WM differ from one company to the other.

The drivers in each company as shown in table 1 below are analysed.

Drivers for WM in company A

The highest internal driver in Company A is the company vision to be a sustainable company. This vision serves as the basis for all environmentally related activities within the company. The sustainability manager of the company describes the company's vision in the extract below:

At Company A, sustainability, it really is everything. Whatever our impact is, whether its construction, or maintenance, or anywhere we operate a business, we impact to community, or we deliver a programme of work and we engage with that community, we use materials and manage waste, everything we do is in our sustainability agenda.

Beyond wanting to be sustainable, the company's WM practices are driven by the need to ensure cost is reduced through sustainable material usage. Costs include cost of the materials, the cost of man hours put into the process, the cost for obtaining permits, the cost of transporting waste and charges for the landfilling or disposal of waste. The company considers sustainable WM as a means to cut down cost on construction projects. As a company poised to be industry leaders, benchmarking of their WM performance against other players in the industry is also a key driver. The desire to have a good reputation or image and the trickled down effect on business, acts as a driver of WM activities. The sustainability manager of the company suggested that image is not necessarily 'image' in the eyes of the general public but in the eyes of the client. The demands of clients for specific WM targets or outcomes, (BREEM ratings) is also seen as a major driver for WM within the company.

Environmental concerns also drive WM. The policy to do well for the environment is also seen as a social or moral responsibility as the company recognises the effects of its activities on the environment and the need to curtail such efforts. Legislation as a key driver plays more of a secondary role. This is because, the company reckons they are environmentally friendly and regard legislative demands as pushing for a similar outcome.

Table 1: Drivers of waste management practices in all four construction companies

	Internal Drivers	External Drivers
Company A	Company Sustainability (vision)	Benchmarking of activities
	Cost considerations	Client demands
	Company image/reputation	Government legislation
	Moral and social imperatives	
	Resource availability	
Company B	Cost considerations	Client demands
	Company image/reputation	Benchmarking of activities
	Environmental concerns	Government legislation
	Resource availability	
Company C	Cost considerations	Government legislation
	Company image/reputation	Benchmarking of best practices
	Environmental concerns	Client demands
		Environmental standards
Company D	Cost considerations	Client demands
	Company image/reputation	Government legislation
	Environmental concerns	Benchmarking of best practices
	Moral and social imperatives	

NB: Internal drivers of WM refer to drivers largely dependent on the factors that exist within the control of the company whereas external drivers are drivers outside the control of the company. Drivers are in order of importance based on emphasis by the interviewees.

Drivers for WM in Company B

A key driver of WM in Company B is the concern for the environment and the quest for sustainability. The company has an aspiration to develop a business that has zero impact on the environment through a cradle to cradle approach (Company sustainability report) and this drives to a large extent WM in the company. Sustainability is an integral part of the company's business and the aim is to be able to deliver sustainable solutions to the client. This makes client demands also a very important aspect of WM within the company. Both the environmental policy and resources management plan of the company emphasizes the client as an integral part of their WM agenda. Another key driver of WM practices within the company is cost considerations. The company regards WM as having potential cost savings. The senior environmental manager of the company summed up the relevance of WM to their company in the statement below:

'And how is it relevant to the business? So, by showing that we're a responsible company, it gives us a competitive advantage, potentially, to say that we can reduce

waste and save costs on construction sites and we've got proof to demonstrate that we've reduced waste over time. Also, a lot of clients are starting to have high targets for waste diversion from landfill or, in some cases, zero waste to landfill aspirations, so we can demonstrate that we're working towards that too. I think that's about it.

The company sees government legislation on waste as a key driver of their WM practices. By principle, the environmental policy of the company proposes compliance and beyond compliance where possible (with environmental legislation) as a driver of their activities. For the company, legal compliance has both financial and social impacts and the company makes sure WM practices are in line with compliance demands.

Drivers of WM practices company C

For Company C, the number one driver for WM is financial concerns. This is because the company sees waste generation as a huge financial wastage and puts in every measure possible to reduce the cost of waste to their projects. The company recognises government legislation as a key driver for environmental management and this to a large extent drives the WM practices of the company. As the environmental manager explains, though cost is a key factor, compliance with legislation will not be traded for financial reasons. She ranks legal compliance and cost as the two most important drivers for WM:

I think, in construction, the legal and the finance are equal. Yes, we have to be legal compliant, and providing that one ticks the boxes, the next one is, definitely, finance. Finance would not take over legal compliance.

For company C, client as a driver of WM practices is more of a reputational concern. For the company to be able to attract and win contracts, the company ensures waste is managed sustainably to give the company a good reputation (image). Having a good reputation affects the business you get and this drives WM. Standards and support systems like ISO 14001 also drive WM though according to an interview with the company's environmental manager, these standards do not change much of what they do as a company. The feel good factor with being a contributor to environmental protection is another driver for WM as this company views WM as a moral and social concern. Before the feel good factor is the availability of resources to manage waste. As explained by the environmental manager, managing waste comes with resource demands (human and material resources) and this drives the WM practices.

Benchmarking is another driver for WM within the company as the company reports their performance to UKCG so they can be compared against the industry performance.

Drivers for WM in Company D

The number one driver for WM practices in company D is client demands and this is due to of the type of clients the company deals with. Unlike Companies A, B and C, company D is a management contractor and has a lot of high-street brands as clients. These clients usually set the targets for the levels of waste generation and management. These companies (clients) are more interested in broadcasting their contributions toward environmental management. Such clients expect the contractor to sustainably manage waste to enable them publish their performances in CSR reports. Cost of waste generation is the second most important driver for the company. The company views material wastage as a waste of money and accepts managing waste makes good business sense.

Company image is a key driver for WM for two main reasons: to show the general public that the company is responsible; and to serve as a means to win contracts (from environmentally inclined clients). To show they are a responsible contractor, the company has registered with the considerate contractor's scheme so their activities can be audited. Benchmarking also drives WM practices just like the other companies to show they are doing better than their competitors in the industry. The environmental manager simplifies these drivers in this sentence:

In terms of our organisational structure, I would say, at board level, we're interested in overall project figures meeting customer targets and being able to compete with other contractors and say 'we're actually doing better than you do' kind of thing.

The company regards legislation as a move towards environmental management (protection) and puts in place measures to ensure compliance is achieved at all times. Due to the company's strong commitment to environmental protection, legislation automatically becomes a driver as it seeks a common environmental outcome. It was also gathered that the company due to their commitment to environmental protection sees WM as a moral and social responsibility.

Extent of effect of WM legislation on WM

As can be seen from the analysis above, the drivers for WM practices are multiple fold (Morrissey and Brown, 2004), and the role of legislation in each company differs to a large degree. Whereas for companies like C and D rank legislation as a key driver (Osmani *et al.*, 2008), companies A and B give a lower ranking to legislation as a driver of their WM practices. Though some of companies suggested that legislation is not a key driver for WM in terms of driving activities, all the firms still had structures in place to ensure compliance with government legislation. For this reason, this research investigated the main role played by legislation and the following results emerged.

The results indicate that, compliance with legislation affects the ability of the companies to win work in a number of ways due to its effects on the image of the companies. As deduced from the companies, a history of non-compliance and subsequent persecution for non-compliance are requirements to be reported in bids for new contracts. According to the interviewees, such incidents become a dent on the image of the company and can be the difference between winning a project and losing one. For this reason, there is always the need to ensure legal compliance. This point of non-compliance having a toll on business of the company was summed up by the senior environmental manager of company B in the extract below:

The main reason to comply with legislation, above all, is the risk to future business. If you are prosecuted as a company, there's a massive black mark on your record, which you then have to report in most prequals and tenders that you send to prospective clients. So the prospective clients will say 'have you been prosecuted at all in the past five years?' It's a companywide thing as well, if one site causes a pollution incident, or a breach of waste legislation, then it's a black mark for the whole of the company, it's primarily because of the risk of public perception and winning future work.

All other interviewees shared similar concerns on the effect of non-compliance on the business of their companies. This suggests that the role of legislation in sustainable WM in the construction industry goes beyond just meeting regulatory demands (Morrissey and Browne, 2004). The effects and motivations to comply with legislation are multiple fold and these occur through a complicated cause and effect manner.

IMPLICATIONS OF RESULTS

The results imply that the main drivers for WM in the construction industry, especially for large firms as used in this research, go beyond government legislation (as reported in previous research Osmani *et al.*, 2008; Lu and Yuan, 2010; Wang *et al.*, 2010) and encompass multiple fold drivers (Morrissey and Brown, 2004). As ranked in Table 1, economic concerns, company vision, image and reputation, environmental concerns, and resource availability are the major internal drivers that push companies to manager waste whiles client demands, benchmarking and government legislation are the main external drivers. Cost as a number one driver for WM is not surprising as there is evidence to suggest that on the average about 21-30% of all cost overruns on construction projects can be attributed to material wastage (Udawatta *et al.*, 2015). Hao *et al.*, (2008) also report that due to the profit maximizing nature of firms, cost affects their willingness to adopt environmentally friendly measures. On the issue of client demands driving WM, Manowong (2012) found that clients perceive waste as an extra expense on projects. It is not surprising then that some clients are switched on to the issue of WM. Research by Udawatta *et al.* (2015), suggest that company policies are more influential in construction WM than legislation. Legislation however still has its place (either direct or indirect) as it has the ability to influence WM practices due to the reputational effects persecution for non-compliance has on companies. Negative reputation has a negative influence on image and ultimately the ability to win projects which leads to economic effects (decrease in profitability). For legislation to play this role effectively, the ability of legislators to detect and persecute non-compliance needs to be boosted.

CONCLUSION

As shown in the preceding discussion, there are many drivers for WM within the UK construction industry. These drivers can be grouped generally into economic concerns, client demands, company vision/agenda, reputation and image, environmental concerns, legislation on waste, benchmarking, resource demands for WM, and rating, standards and support systems. The extent to which these factors drive WM differ from one company to the other and these differences are mainly as a result of the vision of the company and the level of importance they attach to WM.

Though some studies have reported that government legislation is the most critical success factor for sustainable WM in the construction industry (Osmani *et al.*, 2008; Wang *et al.*, 2010), the results of this study suggests that, at least for the large firms used in this research, there are a lot more pressing drivers for WM than government legislation. Key among these are cost (financial concerns), client demands, reputation as a sustainable company, and the need to benchmark results against other industry players. Government legislation still remains a driver of WM practices but in most cases plays a secondary role as firms believe (in some cases) they go beyond legal compliance. The effect of legislation as a driver occurs through the negative image a company stands to suffer should they be prosecuted for non-compliance and the trickled down effect of not winning work (economic concerns).

Based on the reasons stated above, this paper recommends that greater attention should be given to these key drivers to move the industry closer to the goal of ensuring a zero waste economy is achieved. For legislation to play a key role in CD&E WM, enforcement strategies that can help detect and prosecute for non-compliance will be a major boost as firms are more concerned with the negative effect of prosecution. Legislation should also be tied to financial incentives and target clients

whose demands act as a key driver for WM. Due to the key role played by clients and the economic drive of contractors, clients can make greater input by tying WM demands to cost implications. For contractors, WM should be given more attention as it makes good economic sense: reduction in the cost of projects due to reduced waste generation; and a positive image which helps increase the possibility of winning work from environmentally aware clients thereby contributing to profitability.

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TOOLKIT TO CAPTURE ENVIRONMENTAL EMISSIONS IN CONSTRUCTION PHASE OF BUILDINGS IN THE AUSTRALIAN CONTEXT

Malindu Sandanayake¹, Guomin Zhang and Sujeeva Setunge

Department of Civil, Environmental and Chemical Engineering, RMIT University, Melbourne, Australia

Buildings consume a large amount of natural resources and generate high volumes of environmental emissions. A number of studies have attempted to quantify these life cycle emissions of buildings. Unlike other phases, emissions at the construction phase of a building include both greenhouse and non-greenhouse gas emissions. Most of the emission studies on buildings have either overlooked or concentrated only on greenhouse gas emissions when considering emissions at the construction phase. On the other hand, the majority of the commercially available software either lacks reliable inventory or involves complex modelling processes to quantify emissions at the construction phase. Many industry personnel and researchers observe the requirement of a simple toolkit which can accurately evaluate emissions at construction phase with minimum effort. Thus the main focus of the study is to develop a toolkit which can estimate and compare emissions due to materials, equipment usage and transportation at construction phase of the building. The emission factors published by United States Environmental Protection Agency, Australian National inventory report and Inventory of Carbon and Energy were adopted to develop the mathematical models in the toolkit to estimate greenhouse and non-greenhouse gas emissions due to equipment usage, transportation vehicles and materials, respectively. The main functions of the toolkit also include comparison of emissions between two construction methods and activities of the project. A case study was utilized to justify the validity and implementation of the toolkit. This developed toolkit will aid researchers and construction contractors to estimate and compare emissions of different construction techniques with minimum effort.

Keywords: greenhouse gas emissions, construction phase, toolkit.

INTRODUCTION

Buildings are known to be a major contributor of natural resources consumption and environmental emissions with studies showing that it contributes 30% of the greenhouse gas (GHG) emissions (Mao et al., 2013). Apart from GHG emissions, buildings may indirectly contribute towards non-GHG emissions due to its heavy equipment utilization at construction stage. Both these emissions may have adverse environmental and health effects in both short run and long run. Therefore a slight opportunity to reduce these emissions would attract significant emission reduction prospects. At initial stages of the building construction industry, the main research focus was to introduce cost efficient buildings with little interest given to the environment. But the introduction of sustainable construction has changed the fundamental research focus towards energy-efficient buildings. These energy-efficient

¹ s3438338@student.rmit.edu.au

building designs typically focus on the use phase of the building in order to provide improved comfort level to its inhabitants. Apart from use phase, a typical building is also associated with emissions due to materials, construction and end-of-life.

Although emission studies have outlined the significance of emissions at use phase, the emissions at other phases cannot be neglected (Guggemos and Horvath, 2005). Focusing only on use phase will not only eradicate the possibilities of reduction of emissions at other phases, but also will eliminate the possibility of the analysing total environmental impact of a building.

Life-cycle assessment (LCA) is a technique that measure environmental impacts of a product or a process over its life cycle (Diakaki and Kolokotsa, 2009). Selection of materials, equipment and construction techniques may influence the total emissions of a building considerably at an aggregated level. Therefore emissions at construction stage should be given more attention. However, Research studies seldom focus on analysing environmental emissions at construction stage due to many complications (Guggemos, 2003). Collection of accurate and reliable on-site data and constant disturbances at the construction site are few of the major issues at the data collection stage that would force researchers to give less consideration on construction stage. Apart from data collection issues, lack of reliable software which can estimate emissions at construction phase is another major issue for studies to approximate or neglect the emissions at construction stage. Thus contractors and designers find the necessity of a toolkit that is able to evaluate and compare emissions at construction phase with minimum effort.

The objective of this paper is to develop a toolkit that is able to estimate and compare environmental emissions at construction stage of a building. A framework was initially developed to identify the functions of the toolkit. The toolkit is able to separately analyse the emissions due to materials, equipment usage and transportation. Knowing the emissions at a lower level will enable the designers and contractors to introduce emission reduction methods during the execution phase. A previous case study from a literature is used to check the accuracy and functions of the toolkit.

TOOLKIT DESIGN AND DEVELOPMENT

Functions and scope of the toolkit

The aim of the study is to include the following functions in the toolkit.

- Analysis of emissions at construction stage with minimum effort
- Assessment of the emission patterns of the construction equipment used
- Emission evaluation between two construction techniques
- Comparison of emissions among the activities of construction stage

The next design step is to specify the scope and system boundary for the defined functions. The system boundary is selected to incorporate all the major activities related to environmental emissions. Emissions due to materials, equipment usage and transportation are considered as the emission sources at construction stage. The emissions from these sources are further divided in to GHG and non-GHG emissions. Non-GHG emissions are pre-dominant in equipment usage and transportation stage due to partial combustion of fuel whereas GHG emissions are significant in materials stage. Previous studies point out that CO₂ emission governs the GHG emissions (AGGA, July 2013; Seo and Hwang, 2001). Therefore the study limits GHG emissions to CO₂ emissions. Figure 1 shows the scope and the system boundary for the toolkit. The scope also classifies the construction stage of a building into

foundation, structure and whole building construction. Foundation and structure construction are given separate consideration because it covers majority of the construction.

Development of the toolkit

Development of the toolkit is based on two key considerations. The first was to decide the user inputs for the toolkit. Three important factors had to be taken into consideration when deciding these inputs. Firstly, the inputs should not be complicated, secondly it should be user friendly and finally the inputs should make a comprehensive analysis. The second stage was to decide system specific data and inputs steps to deliver the desired outputs in a simplified manner. Figure 3 describes the calculation steps of the toolkit with clearly specifying the user input data, system generated data and information on calculation steps. Explanation of the working flow of the inputs is given in the following sections.

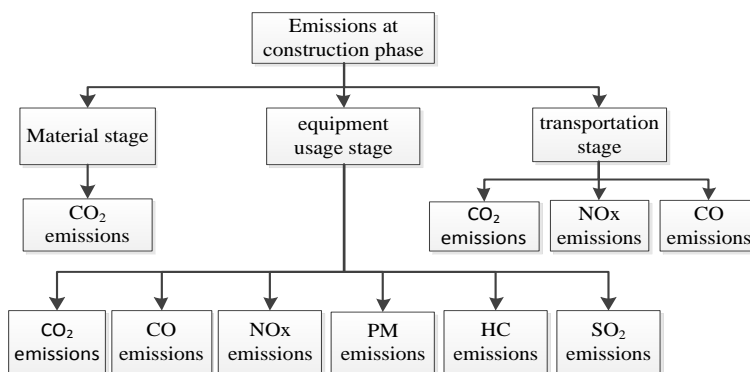


Figure 1 Scope and system boundary of the study (Toolkit)

Mathematical models/ emission factor inventories used

The mathematical models are developed based on the emission factor inventories selected. Emission factors published by United States Environmental Protection Agency (US EPA) are used to determine non-GHG emissions from equipment usage (Exhaust, 2002) whereas emission factors published by Australian Greenhouse Gas Accounts are used for calculation of GHG emissions from transportation and equipment usage (AGGA, July 2013; Exhaust, 2002). US EPA factors were found to be a comprehensive set of emission factors to evaluate non-GHG emissions (Jung et al., 2009). Emission factors for materials were obtained from Inventory of Carbon and Energy (ICE) as it was one of the most commonly used comprehensive database for material emission factors (Hammond and Jones, 2008).

Initial development using excel-based spread sheet

The mathematical models and design steps of the toolkit were first employed in an excel spread sheet to understand the execution and complication issues of the toolkit. Macro settings and mathematical functions available in excel were used to develop the working flow of the toolkit. Figure 4 shows the working flow for the intended toolkit. The first three steps are project specific inputs whereas the final two steps are analysis based inputs. The first step is to enter the project specific details into the system.

Step 1a) Scope of the analysis – The user has the option of considering either foundation, building structure or the whole building construction for the emission study.

Step 1b) Project information – General project information such as building use, height and location of the building, number of floors are requested from the user. This information is later utilised in the comparative analysis.

Step 1c) Building information – In this step the user is invited to input building specific information such as construction type, total floor area, plan area, contractor name, foundation and structure construction type and soil type. Contractor name is an optional input and the others are compulsory inputs.

The next step is to input the machines, materials and vehicles used during construction stage.

Step 2a) Machine and equipment details – Total usage hours of every machine used at site should be entered in this step. Machine specific details such as machine type, make, model number, power (in hp), technology and cumulative usage are also required to carry out the analysis. A machine's emission pattern is different from one another and therefore every machine will have a unique emission factor for each emission substance. Thus a database is created to incorporate all the unique emission factors (HC, CO, NO_x, SO₂, CO₂ and PM) of the different construction equipment. These emission factors and the corresponding machine characteristics are sorted based on the model number of the machine. The user has the privilege of loading the corresponding machine details once the model number is entered if it is already in the database. If not available, the user can create a new machine profile using a new entry by typing the machine type, model number, power and technology. Technology refereed here is an emission standard (usually tier 1, 2, etc.) which can be obtained from the technical statement. A view of the database for construction equipment emission factors is shown in Figure 2.

Step 2b) Transportation details – The user is required to input all the details of transportation vehicles used during the construction. Vehicle specific details such as type of vehicle, model year, category, fuel type and project specific details such as cumulative km's travelled, fuel consumption and the distance travelled are the required inputs for calculating emissions from transportation.

Step 2c) Material details – Under material details, the total quantity of the materials used (in kgs) should be entered. The user has the option of selecting a material category which is already in the database. If the material is not available it is required to manually enter the concerned material.

The third step is to record the activities corresponding to the materials, machines and transport vehicles entered in the preceding step. If emission comparison is not required at activity level, the user has the option of skipping this step.

Step 3 a) Activity details – Activities in construction and the corresponding duration in hours needs to be entered in this step.

Step 3 b) Assign input data to activities – Assign machines and materials (entered in Step 2) to the activities entered in the previous step.

Step 3 c) Add quantities – Add quantities to the assigned materials and machines for each activity introduced in the previous step.

Once the required information is entered, the toolkit will calculate the emission rates for materials in g/kg, for equipment in g/hr and for transportation vehicles in g/km. When assigning machines to activities in Step 3b, the toolkit will suggest selecting the equipment or vehicle with the minimum emission rate wherever possible. At this stage

the user is given the option to choose the combination suggested by the toolkit or the option according to the user’s preference.

Step 4 a) Select the required analysis options – This step enables the users to select the required analysis options. At this step the user is given the option to compare emissions completely, at activity level, at equipment level and between two different construction techniques.

Step 4 b) Comparison required – This step is required if the user intends to compare the current emissions with another construction project of similar kind.

The final step is to interpret and validate the results obtained.

Step 5 a) Results interpretation – The obtained results are then directed towards impact categories by introducing characterising, normalisation and weighting factors. Five major impact categories, Global warming potential (GWP), Acidification potential (AP), Eutrophication potential (EP), Photochemical Oxidant formation potential (POFP) and Human Toxicity potential (HTP) are used in the analysis. The weighting factors are developed to understand the significance of the impact categories based on three perspectives, global, regional and local level. These perspectives represent different geographic levels and the significance of emissions at construction on the three levels will be compared.

Step 5 b) Results validation – Sensitivity analysis will be carried out to check the impacts of the inputs on the output. First the user is given the option to choose a minimum and maximum range of the inputs that are likely to change the outputs. Then recalculation is done for 2500 randomly generated inputs between the ranges specified by the user. The resulting output is then utilised to draw conclusion on which inputs have more impact on the output. Uncertainty analysis will be carried out by using Monte-Carlo simulation. The results obtained are then to be verified by standard software (@ RISK).

The interpretation and validation processes involve broader analysis which is out of the scope of this paper and will be discussed in a different publication.

TOOLKIT FUNCTIONS AND IMPLEMENTATION

A case study of a previous published literature study on horizontal directional drilling (HDD) is used to check the functions and the consistency of the toolkit (Sihabuddin and Ariaratnam, 2009). The project specific details of the case study are given in Table 1. Only emissions from equipment are considered to explicate the working flow of the toolkit. An ID number is generated for equipment and activities as shown in Table 1 to be used for comparison purposes. The results obtained by the toolkit and the original results are then compared to check the consistency of the toolkit.

MACHINE TYPE	MAKE	MODEL	Fuel Type	POWER (hp)	TIER	LIFE SPAN	LF	BSFC	HC			CO			NO _x			PM			CO ₂	
									DF	TAF	EF	DF	TAF	EF	DF	TAF	EF	DF	TAF	EF		
Excavators	Hitachi	ZX 200LC-3	Diesel	164	3	8000	0.59	0.367	0.027	1.05	0.184	0.151	1.53	0.867	0.008	1.04	2.5	0.47	1.47	0.22	1.01	0
Excavators	Hitachi	ZX 210H-3	Diesel	164	3	8000	0.59	0.367	0.027	1.05	0.184	0.151	1.53	0.867	0.008	1.04	2.5	0.47	1.47	0.22	1.01	0
Excavators	Hitachi	ZX 210LCH-3	Diesel	164	3	8000	0.59	0.367	0.027	1.05	0.184	0.151	1.53	0.867	0.008	1.04	2.5	0.47	1.47	0.22	1.01	0
Excavators	Hitachi	ZX 210K-3	Diesel	164	3	8000	0.59	0.367	0.027	1.05	0.184	0.151	1.53	0.867	0.008	1.04	2.5	0.47	1.47	0.22	1.01	0
Excavators	Hitachi	ZX 210LCK-3	Diesel	164	3	8000	0.59	0.367	0.027	1.05	0.184	0.151	1.53	0.867	0.008	1.04	2.5	0.47	1.47	0.22	1.01	0
Excavators	Hitachi	ZX 210-5	Diesel	159	4	8000	0.59	0.367	0	1	0.131	0	1	0.867	0	1	2.5	0	1	0.009	1	0
Excavators	Hitachi	ZX 210LC-5	Diesel	159	4	8000	0.59	0.367	0	1	0.131	0	1	0.867	0	1	2.5	0	1	0.009	1	0

Figure 2 Database created for construction equipment emission factors

The case study was chosen because it replicates the emission substances similar to the toolkit and could effectively be used to emphasize the functions of the toolkit.

Web based toolkit development

Excel based toolkit is expected to be further developed into an online web- based toolkit which will provide easy access. This web based toolkit is still under development and will be uploaded in the near future.

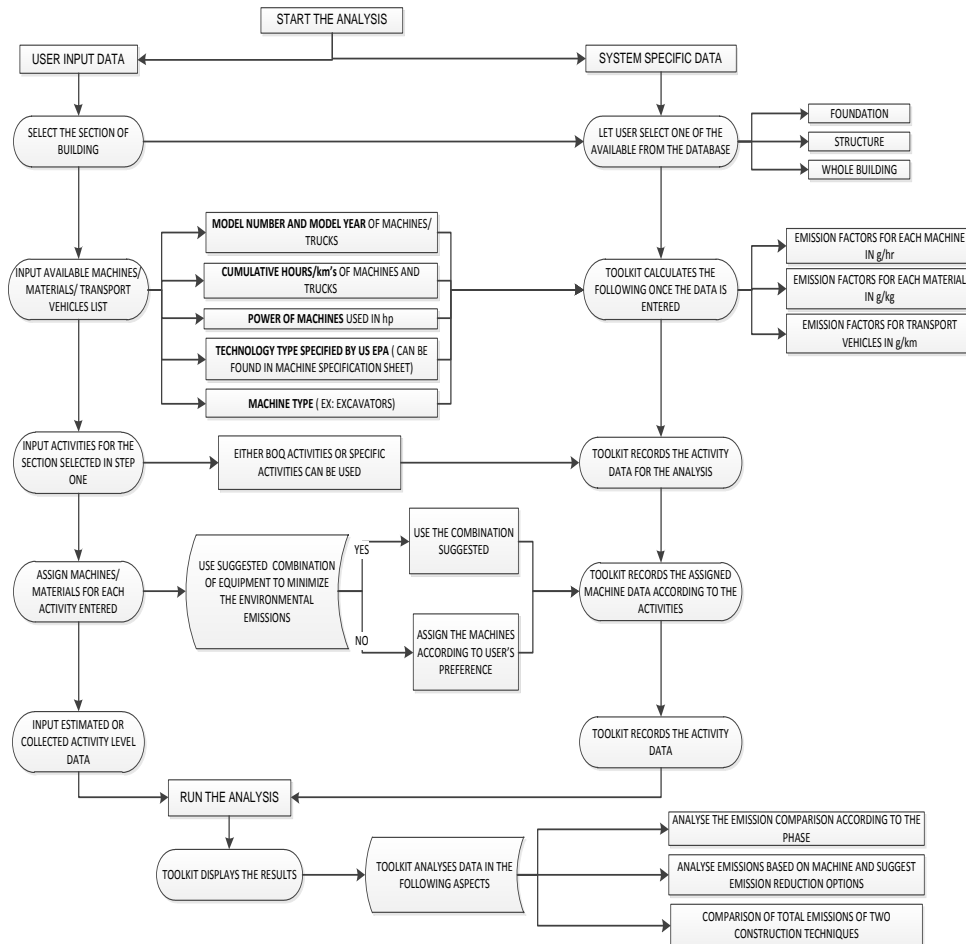


Figure 3: A general layout on the calculation flow of the toolkit

The developed toolkit is able to capture emissions at all stages of construction in a building. At this stage toolkit limits the emissions evaluation to major construction stages of a high-rise building. The authors intend to further develop it into a toolkit which is able to capture emissions all the construction stages. A total up to 1000 equipment, materials, transport vehicles and activities can be analysed from the toolkit.

These project details are entered into the toolkit according to the steps shown in Figure 7. The comparative results shown in Table 2 illustrate that apart from CO₂ the deviation of results are less than 5%. The reason is that since CO₂ emissions are dependent only on the fuel consumption, the toolkit use fuel based emission factors whereas the original study uses a default fuel consumption factor which depends on the power of the machine. This deviation is comparatively high because the total emissions are much smaller (in grams) and becomes negligible when the amount of emissions becomes larger.

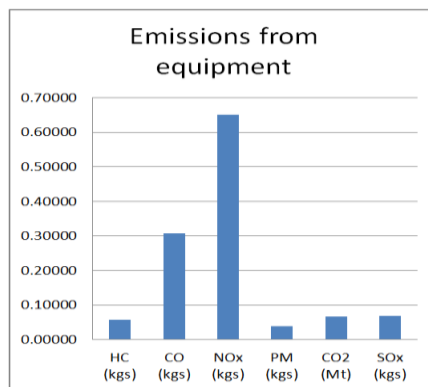
Table 1 Equipment data of HDD case study

Equipment Details						Activity Details		
ID	Name	Engine model	Model year	Rated hp	Cumulative usage (hrs)	ID	Name	Time (mins)
E1	Backhoe	Tier 2	2007	90	12	A1	Excavation of pits	15
E2	Vacuum truck	Tier 2	2006	36	906	A2	Potholing for utilities	20
E3	Drill rig	Tier 1	2000	165	2200	A3	Pilot hole	40
						A4	Pre-ram	30
						A5	Pull back	20
E4	Fluid mixer	Tier 1	2003	8	112	A6	Supply of drilling fluid	90

Table 2 Comparative results of the toolkit with the original results

	HC	CO	NOx	CO ₂	PM	SO ₂
Original results (in g)	56.6	305.8	638.1	49900	37.65	68
Toolkit results (in g)	57.31	306.72	650.60	66700	39.24	67.86
Deviation (%)	1.3%	0.3%	1.95%	34.2%	1.6%	-3.15%

Emissions from equipment							
ID	PROJECT NAME	HC (kgs)	CO (kgs)	NOx (kgs)	PM (kgs)	CO ₂ (Mt)	SO _x (kgs)
P001	Horizontal drilling	0.05731	0.3067	0.6506	0.0394	0.0667	0.06786



PRINT RESULT NEXT

Figure 4 Total emissions due to equipment in case study

RESULTS AND DISCUSSIONS

One of the potentials of the toolkit is that the results obtained can be analysed in different perspectives. The analysis shown in Figure 5 shows the emission analysis based on the activities and Figure 6 illustrates the comparison of emissions between the equipment used at site.

ACTIVITY ID	ACTIVITY NAME	MACHINE ID	HOURS	HC (kg)	CO (kg)	NOx (kg)	CO ₂ (Mt)	PM (kg)	SO ₂ (kg)
A1	Excavation of entry & exit pits	E1	0.25	0.018922	0.136821	0.116328	0.013223	0.009341	0.010534
A2	Potholing for utilities	E2	0.33	0.003557	0.029163	0.054074	0.007073	0.005755	0.013004
A3	Pilot hole	E3	0.67	0.011200	0.028839	0.18690	0.01749	0.007869	0.013933
A4	Pre-ram	E3	0.50	0.008400	0.021630	0.140171	0.013117	0.005902	0.010450
A5	Pullback	E3	0.33	0.005600	0.014420	0.093448	0.008744	0.003934	0.006967
A6	Supply of drilling fluid	E4	1.50	0.009627	0.075851	0.059684	0.007054	0.006639	0.012968

FINISH

PRINT RESULT

Figure 5: Analysis of emissions based on the activities

MACH . ID	MACHINE NAME	MODEL NUMBER	POWER (hp)	TOTAL OPERATION HOURS	TOTAL EMISSIONS FROM EACH MACHINES						EMISSION RATES OF MACHINES (g/hr)					
					HC (kg)	CO (kg)	NOx (kg)	CO ₂ (Mt)	PM (kg)	SO ₂ (kg)	HC	CO	NOx	CO ₂ (kg/hr)	PM	SO ₂
E1	Backhoe	CASE580	90	0.250	0.01892	0.13682	0.11633	0.01322	0.00934	0.01053	75.687	547.282	465.311	52.892	37.364	42.1362
E2	Vacuum truck	FX30	36	0.333	0.00356	0.02916	0.05407	0.00707	0.00575	0.01300	10.672	87.4883	162.222	21.219	17.264	39.0126
E3	Drill Rig	D36	165	1.500	0.02520	0.06489	0.42051	0.03935	0.01771	0.03135	16.801	43.2591	280.343	26.233	11.803	20.8997
E4	Fluid mixing system	DT1000	8	1.500	0.00963	0.07585	0.05968	0.00705	0.00664	0.01297	6.4179	50.5672	39.789	4.702	4.426	8.64519

NEXT

PRINT RESULT

Figure 6 Analysis of emissions between equipment used

The results obtained by the toolkit draw several important observations on emission analysis perspectives. A close inspection on the results at Figure 6 shows although E3 has the highest emissions in almost all the emission substances, E1 records the highest emission rates for all the emission substances. This is because E3 is used more at site compared to E1. When a number of same types of machines are used, the emission rates comparison provides a useful mode for effective allocation of work for each machine. The emission comparison at activity level shown in Figure 5 provides a detailed breakdown of emission distribution in different activities. The results show that activity A1 has the highest emissions for most of the emission types. This is because machine E1 with the highest emission factor is utilised for activity A1. It can also be observed that although having maximum emissions, activity A1 has the least operation hours. This clearly shows that the duration is not the only factor that decides the amount of emissions and careful allocation of machines into critical activities can reduce the emissions considerably. This machine allocation becomes critical when the whole construction of the building is considered where several machines are used in one activity.

CONCLUSIONS

Construction phase may release substantial amount of GHG emissions as well as non-GHG emissions. Different construction techniques may have different levels of emissions based on the selection of materials, equipment and transportation. A comparative tool which is able to estimate and evaluate the emissions before the execution phase would enable the designers and the contractors to adopt energy reduction options. The study focus was to develop a toolkit which enables the users to compare the emissions at construction phase effectively with minimum effort. The developed toolkit is able to estimate and compare GHG and non-GHG emissions between two construction techniques. It can either evaluate the emissions of a completed project or estimate the emissions of a future scheduled project. It also can compare emissions between construction equipment which will aid in understanding emission reduction possibilities. The case study results confirmed the capacity of the

toolkit to estimate and compare emissions at different construction techniques, activity level and at different emission stages. The toolkit can be further developed which can be used by designers and contractors to reduce emissions before commencing the construction.

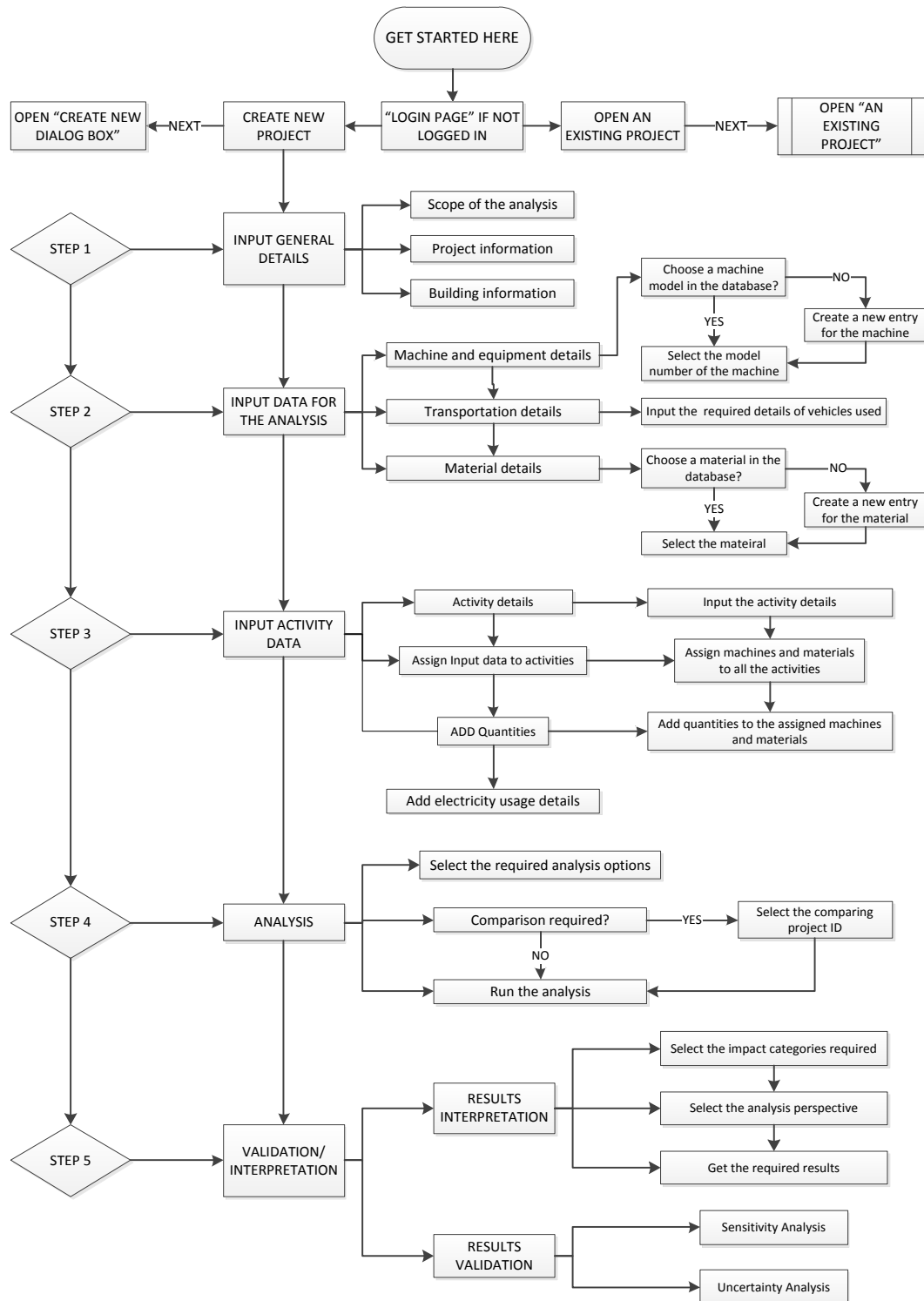


Figure 7: Working flow of the toolkit

FUTURE RESEARCH

The intended objective of the paper is to introduce a toolkit that is able to evaluate and compare emissions at construction stage. The next stage will be to introduce

weighting criteria for emission substances to compare them from different impact categories. Further studies will be carried out to increase the accuracy and reliability of the toolkit using case study results and statistical analysis methods. The toolkit will be further developed to evaluate the complete activities at construction phase with having more user input options. Future research and studies are also encouraged on carrying out optimization between the cost and the emissions to identify the ideal selection of construction materials and equipment for different construction techniques.

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THE ASSESSMENT OF GREENHOUSE GAS EMISSIONS FOR EVALUATING ACTUAL ROAD CONSTRUCTION OPERATIONS

Mathagul Metham¹ and Vacharapoom Benjaoran

School of Civil Engineering, Institute of Engineering, Suranaree University of Technology, Muang District, Thailand

Assessment of greenhouse gas emissions of products using the life cycle inventory analysis (LCI), can be performed in both the pre- and/or post-construction phases of road construction. For the pre-construction phase, a bill of quantity (BOQ) is used to calculate emissions, whereas, in the post-construction phase, emission calculations are based on the actual work done. Road construction is one of the construction sectors which requires long project time and a great deal of machinery. The actual amount of total resources used is probably different from that which is stated in the BOQ. In general, greenhouse gas assessments consider only data from either the pre-construction phase or the post-construction phase. However, it is possible to control and monitor actual resource-utilization by comparing change at the post-construction phase in relation to the pre-construction phase. This can reveal construction operation performance and lead to the development of methods or construction operations resulting in a reduction of greenhouse gas emissions. The current research uses three road construction projects as case studies. It aims to improve the EIO-based inventory calculations of machinery used in road construction by adjusting the proportion of usage hours for that machinery. It achieves this by comparing actual data relating to energy, materials and machinery consumption with BOQ data. The results of this comparison help to identify the factors and causes that influence operational performance (in terms of greenhouse gas emissions) and lead to improvements in road construction operations. The key findings from emission calculation between pre and post-construction phases were that the project A had decreased the greenhouse gas emissions by 3.8%, contradictory with project B and C which had increased more gas emissions by 5.0% and 0.6% respectively. Considering with these figures it is reflected the resource management efficiency of each project. The main cause of greenhouse gas emissions on each project was the usage machinery which depended on the project period.

Keywords: greenhouse gas, monitoring, resource-utilization, road construction.

INTRODUCTION

Greenhouse gas emissions evaluation according to the life cycle assessment (LCA), according to the International Organization for Standardization (ISO); 2006 standard series, as displayed in Fig. 1, consists of 4 principal steps: 1. Goal and scope definition; 2. Life cycle inventory analysis (LCI); 3. Life cycle impact assessment (LCIA) and 4. Interpretation (Crawford, 2011). The LCI is an important step for compilation of quantities of inputs and outputs of concerned products throughout their life cycles. LCA may be conducted both prior to construction by the designer, policy

¹ D5740178@g.sut.ac.th

maker and planner, to aid in the decision to choose the appropriate construction design, as well as post-construction by field operators and program evaluators, to evaluate the actual impact. Data sources to be entered into the inventory would differ according to the evaluation period. In other words, if evaluating prior to construction, the resource quantity data would be obtained from the design documents (pre-qualification data and BOQs), while post-construction data would be compiled from actual operations (data from field reports) and variety while in construction.

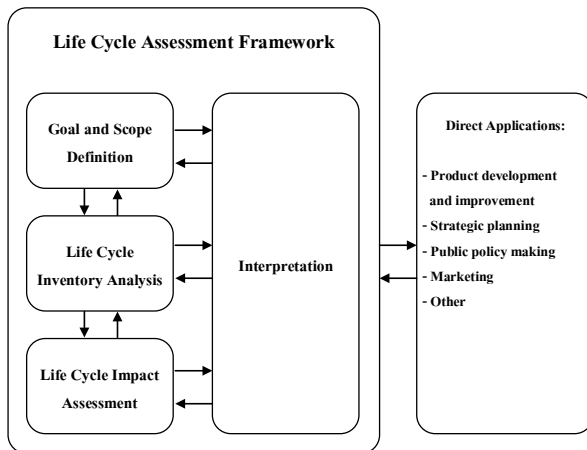


Fig. 1. LCA framework based on ISO 14040: 2006

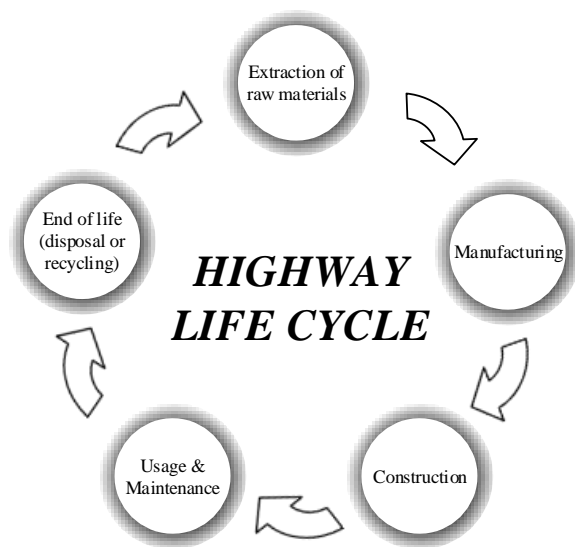


Fig. 2. Life cycle of highway construction product

Road construction uses a large amount of equipment or machinery in each project (Park *et al.*, 2003; Payothornsiri and Phainai, 1999), indeed, much more than other types of construction. Such machinery is referred to as capital goods, that is, a goods or product that has already passed through the productions process and is used as part of another production process (BSI, 2008). Most of road construction machinery is that of the heavy type, such as backhoes, loaders, dump trucks, motor graders, asphaltic pavers, for example, and is part of the highway construction life cycle as shown in figure 2. Moreover, the construction process consists of a variety of activities which are of long duration in time along the life cycle of each project as well. However conducting an LCI at different time may cause differences in data obtained which maybe lead to different greenhouse gas emission evaluations as well.

It would be useful to compare such evaluations as to ascertain the efficiency of operations and to be data supporting methods or process development for improvement in that construction. Furthermore, previous studies do not considered these, most of their studies would be focussed on either pre or post-construction phase. If these is such follow up comparison of similarities or differences, there might be to answer the following questions:

Are the differences between evaluations from the BOQ and field reports?

If there are differences, what are the possible causes? Furthermore which source would be more appropriate for gas emission evaluations?

How can one use results from both sources data to the advantage of any aspect of construction development?

This research has considered three highway construction projects as to propose a directive to help improve data collection of input-output items concerning machinery in production basis of Economic Input-Output based (EIO-based), adjust proportions according to actual hours of operation. The evaluation provides a comparison actual field reports and BOQ data of energy, materials and machinery consumption, as to indicate factors and causes of efficiency of construction operations in terms of greenhouse gas emissions, useful for the improvement of hypotheses or data prior to construction, leading to improvement of the general construction process.

INVENTORY ANALYSIS OF ROAD CONSTRUCTION

The LCI is a procedure designed to collect input-output data in the production process. Generally, the GHG emission-assessment is performed using either an input-output-based (IO-based) or a process-based inventory approach (Cass and Mukherjee, 2011). Most of time, the process-based approach is used to generate an inventory process for each step or each activity of products system, which can generate specific input-output data for each process. The approach can produce an accurate inventory if accurate information for input-output data is obtained at each step of the process. Complicated processes render accurate information over their entire processing difficult to obtain it is determining the inventory accurately is a challenge. Furthermore, the approach requires a huge amount of time and money. The factors that limit the use of LCI arise from accurate machinery assessment in terms of production since the entire production process cannot be accessed. These reasons have led us to develop an approach to reduce they limitation.

The IO-based approach depend on an evaluation such as an energy input-output model or an economic input-output-based model (EIO) etc. A prevailing approach is EIO-based, which was developed in the 1970s. The approach uses information about the economic transactions of resources, and estimates the environmental emissions resulting from the materials and energy input resources required (Hendrickson *et al.*, 2006). This approach of output information, represented average environmental impact in each industries. Limitations in the complex production processes of capital goods can reduced by the EIO-based approach. However, this approach has some disadvantages which was also average of industries. Perhaps, the results are inconsistent with the actual activities or projects operation, as in the case of the machinery in construction work (Park *et al.*, 2003; BSI, 2008). This approach considers as if the machinery is used up in one project but in practice, most of machinery can have a useful life longer than one project and be reused in the next project. Therefore, the calculated emission levels will be exceeding and unreasonable.

The hybrid LCA approach reduces the disadvantages by combining the advantages of both approaches. The approach leads to a better complete inventory (Crawford, 2011). Principles of this approach try to eliminate or avoid errors arising from the processes-based upstream of the supply chain (extraction of raw materials and manufacturing), and to remove the disadvantages of the EIO-based approach downstream of the supply chain (construction, usage and maintenance and end of product life). Therefore, the hybrid LCA approach is more efficient for estimating environmental impacts on road construction projects.

The inventory from collecting amount of materials and equipment are frequently performing at the pre-construction phase, as in Park *et al.* (2003) who evaluated the GHG emissions of highway construction projects. Cradle-to-grave was boundary definition for the products (manufacturing of construction materials, construction, maintenance and removal and reuse). The study focuses on ways to help assess more environmental friendly design options, with special attention about energy consumption in project activities. The hybrid LCA used for the inventory analysis collected the input-output data of the typical highway cross section from BOQ. In addition, the research of Kofoworola and Gheewala (2008) uses office building construction projects in Thailand as case studies. It aims to identify the factors and causes that influence environmental emissions from that construction and lead to improvements for sustainable construction operations.

Also, data were collected from actual work done in the post-construction phase. Cass and Mukherjee (2011) evaluated emissions generated during the entire life cycle of the project as assessed by the hybrid LCA approach. The inventory was collected from actual on-site data during the construction stage from information on emissions assessment of pavement rehabilitation and reconstruction project. The main purpose was to help support decisions of government policy makers to bring about a reduction of GHG emissions and minimize environmental impact in the long term. In addition, the research of Jiamvoraphong and Tongthong (2012) uses activities relating to the installation of pre-cast concrete walls as a result of a case study of a building construction project. It also collected labour and materials transportation information.

Monitoring or checking is a tool or technique of construction project management. Continuous control and monitoring of all the processes leads to improvements and greater operational efficiency. It is part of a set of procedures for production improvement, known as the Deming Cycle (Jiradamkerng, 2011) which consists of: a plan, the identification or planning to set up sequences, steps and procedures about the activities; do, performing actions or activities based on the objectives; check, monitoring the performance and comparing with the product of the previous plan; action, taking action on the basis of comparative results leading to revision or improvement leading to better products. Also, the cycle was continuously applied throughout the product processes. Performance-checking is important for project control and the actual operation and management practices need to be monitored following the objectives and the plans determined (Gould and Joyce, 2002). The checking of project-development has many aspects such as cost, materials, resources and energy that are their exactly objectives or not. Abnormal results from the plan can lead to sudden improvements or revision. Therefore, the checking or monitoring is the appropriate performance tool for product improvement.

RESEARCH METHOD

This research is focussing on the highway construction impacts assessment. It conducted a comparison between the data from two difference sources. These data were used to prepare the inventories for GHG emissions assessment. The functional unit was defined as lane-km and a boundary system was cradle-to-gate (or business-to-business: B2B), as shown in double dash line and shaded area (Fig. 3). The information consists of the main items on a highway construction project, i.e., earth work: soil excavation, embankment production and embankment construction; surface work: aggregate extraction, aggregate production, petroleum refinery, bitumen production and pavement construction; bridge and drainage work: lime stone extraction, iron ore extraction, equipment production, cement production, steel production and bridge and culvert construction. These include the usage of machinery in the construction stage, which represented by “*M*”, the amount of transportation which represented by “*T*”, and the installation of road safety and road sign. This study focuses only on the extraction of raw materials, the manufacturing, and the construction stages. It uses the emission factor (EF) from the conference of Intergovernmental Panel on Climate Change 2007 (IPCC, 2007) for calculating the GHG emissions on the operation level. The EIO-LCA on-line tool was used to evaluate the emissions from information about industry transactions - purchases of materials and/or machinery by one industry from other industries. This tool can be accessed through the Carnegie Mellon University website (EIO-LCA, 2014). The environmental impacts assessment considered only the global warming impact, which presented in terms of tons of carbon dioxide equivalent (t CO₂-e) and based on the multiplying factors introduced by IPCC’s GWP100 (IPCC, 2007). Moreover, all machinery cost must be converted to the present value in year 2002 by using the formula in Equation 1, and also converted to US dollars (43 THB/1 USD approximately) (BOT, 2014). Consequently, the inventory cost were consistency with the EIO-US 2002 Benchmark Model - purchaser price (EIO-LCA, 2014)

$$COST_{2002} = COST_X (1 \pm i)^n \quad (1)$$

where $COST_{2002}$ = the present value of cost in year 2002; $COST_X$ = the cost in year X which have to be converted) using minus if X is later than 2002 or plus if earlier than 2002); i = inflation rate) assumed to be 3%); and n = the amount of different years from X to 2002.

Consumptions at Pre-Construction Phase

The inventory which presents the amount of resources consumption at the pre-construction phase was prepared by using the BOQ stated in the contract. The inventory life cycle analysis or LCI in Fig. 3 (work flow of activities), the most activities were executed by the heavy machinery. The preparation of the machinery inventory was very complicated process but the EIO-based approach for evaluated the environmental impacts (depend on category of impacts) was selected and implemented in this study. At manufacturing stage, the machinery emissions do not considering the reused effect such in the research of Park *et al.* (2003). Therefore, this research presented its impacts by the repetition at pre-construction phase, it modified the proportion of the repetition from Cass and Mukherjee (2011) at post-construction phase as shown in Equation 2.

$$M_{BOQ} = \frac{Q}{P \times N} \quad (2)$$

where M_{BOQ} = usage hours of machinery by adjusting the proportion for BOQ; Q = the amount of required products; P = production rate; and N = useful life of machinery (assumed to be 10,000 hrs)

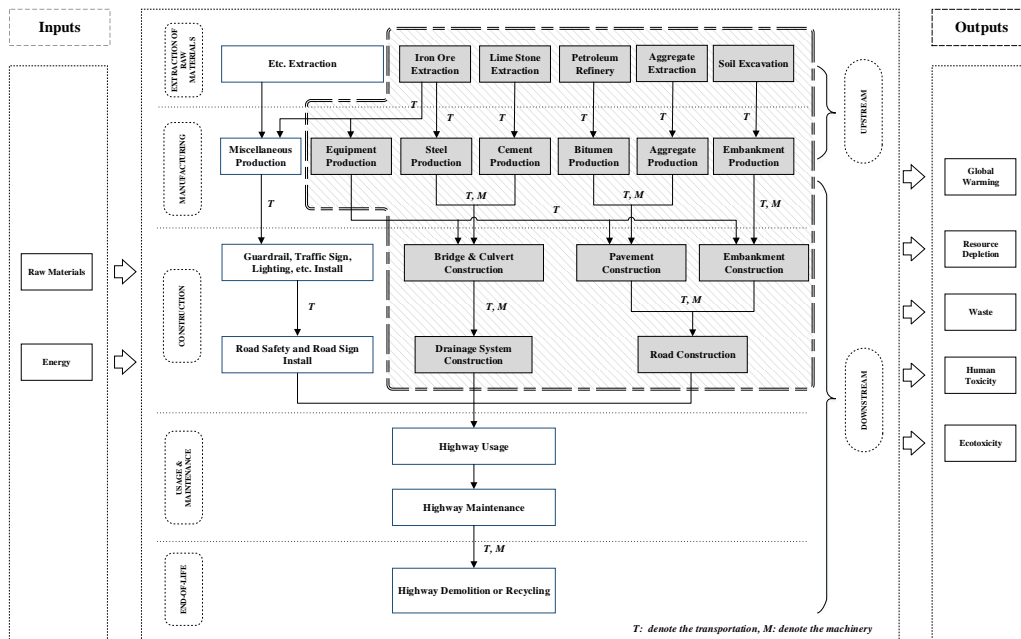


Fig. 3. Work flow of input-output for highway construction product life cycle and boundary study

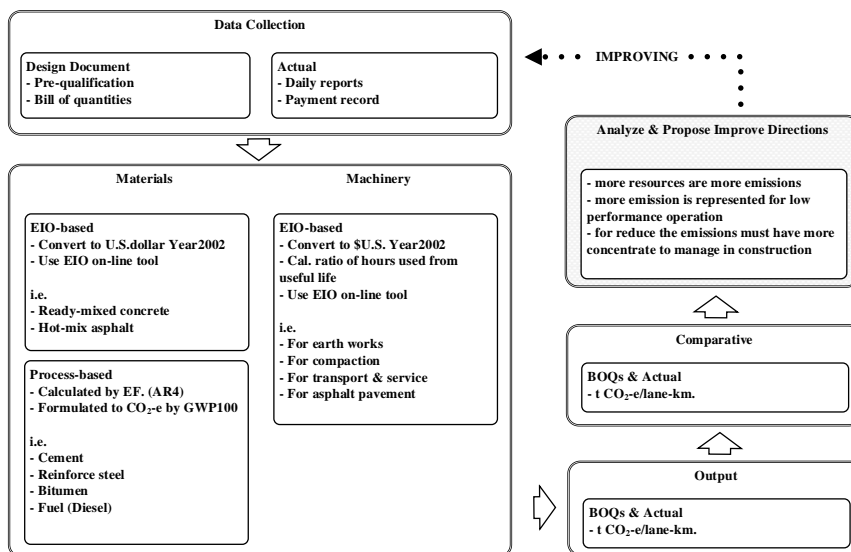


Fig. 4. Procedures of the evaluation GHG emissions

Consumptions at Post-Construction Phase

The inventory which presents the amount of resource consumption at post-construction phase was prepared by using the actual work done data on-site. These actual work done data had to be consistent with the payment record report. Cass and Mukherjee (2011) considered the repetition of that machinery manufacturing impacts. Therefore, at the post-construction phase, the actual amount of on-site usage hours have already been received. The adjustment proportion of machinery with the useful life as shown in Equation 3.

$$M_{actual} = \frac{h}{N} \quad (3)$$

where M_{actual} = the adjusted usage hours of machinery; h = the amount of usage hours from the on-site report; and N = the useful life of machinery (assumed to be 10,000 hrs).

The GHG emissions assessment method, which is proposed in this study, applies the proportion of machinery usage to adjust the impacts and can give more reasonable results. The assessment procedures are shown in Fig. 4.

RESULTS

In this research, the highway construction projects in Thailand were selected as case studies studied to evaluate the environmental impacts of construction products. These cases were used to demonstrate the LCI that was related with the reuse of machinery manufacturing and machinery usage, and relied on the BOQ and actual work done data. Three case studies including project A, B, and C have a similar typical cross section of the highways. This is to illustrate the trend of comparative results. All case studies have two lanes of roadway construction and shoulder with 11.00 metres width and use the asphaltic concrete type of pavement. At the time of data collection (in December, 2014), the projects have approximately 95%, 70%, and 98% progresses, respectively.

Table 1: The resources consumption of case studies.

Resources	Unit	BOQ	Actual	BOQ	Actual	BOQ	Actual
Earth Work		Project A		Project B		Project C	
- Cement	cu.m.	3,000	5,997	1,769	1,659	-	-
- Embankment	cu.m.	395,000	434,158	165,461	231,023	339,900	347,563
- Selected Material "A"	cu.m.	-	-	-	-	44,100	44,407
- Soil Aggregate	cu.m.	100,500	98,413	47,034	57,944	97,000	94,609
- Soil Agg. Type Base	cu.m.	75,000	74,848	44,226	41,469	67,500	65,661
Pavement							
- Bitumen	sq.m.	735,000	730,104	426,676	397,925	682,100	605,527
- Asphalt Concrete	sq.m.	727,000	710,485	423,861	398,989	632,900	606,797
Structures							
- Steel	tons	100	107	84	52	182	201
- Concrete	cu.m.	1,476	1,586	892	350	1,903	1,531
Fuel							
- Diesel	litre	846,936	580,592	601,504	687,471	991,121	1,276,255

Table 1 shows the items of the main construction materials, which are consumed by the activities such as earth work, structure work, and surface work etc. All data were collected from the daily reports by field inspectors. Table 2 shows the machinery usage in the analysis of the case studies, by assuming that usage hours were 7 hrs/day for the BOQ, and were 8 hrs/day for the actual work done. Their machinery price data were supported by both contractors and Metro Machinery Co., Ltd.

The comparison results of the total amount of emissions between pre and post-construction phases from the three case studies indicated that. Project B has the most different GHG emissions 12,414.82 t CO₂-e/lane-km, which had the increased

emissions by 5.0%. Secondly, project C had different emissions 1,605.56 t CO₂-e/lane-km (increased emissions by 0.6%). On the other hand, result for project A had different emissions 10,285.25 t CO₂-e/lane-km (decreased emissions by 3.8%). Table 3, it is presented the different percentage of GHG emissions, and reflected the bar chart as shown in figure 5.

Table 2: The machinery usage hours of case studies.

Machinery	Capacity	Price	BOQ	Actual	BOQ	Actual	BOQ	Actual
(Earth Work)			Project A		Project B		Project C	
- Backhoe	128 hp	100,378	4,608	15,584	2,750	4,544	3,966	15,216
- Bulldozer	165 hp	112,670	7,065	408	4,570	NA.	5,941	3,200
- Motor Grader	150 hp	110,687	9,522	18,000	6,390	8,984	12,890	16,664
- Wheel Loader	220 hp	100,378	3,911	6,656	3,028	1,760	3,241	1,240
(Compaction)								
- Pneumatic Tire Roller	9 T	47,415	11,427	26,520	8,193	9,520	12,225	13,200
- Vibrating Roller	152 hp	61,091	8,519	18,784	5,777	8,592	9,694	18,976
- 3 Wheel Steel Roller	9.5 T	29,712	1,454	1,896	1,208	376	3,753	3,728
(Service)								
- Water Truck	16,000 T	38,991	9,772	14,904	6,810	9,944	10,863	14,832
- Dump Truck	10 cu.m.	40,403	5,816	73,384	4,830	34,496	5,063	37,856
(Pavement)								
- Asphaltic Mixing Plant	160 T/hrs	861,190	1,454	NA.	1,208	NA.	NA.	NA.
- Asphaltic Distributor	6,000 L	31,408	1,252	2,232	1,033	176	1,170	640
- Asphaltic Paver	114 hp	238,170	1,454	1,896	1,208	272	1,266	592

Note: Machinery prices in 2002 USD.

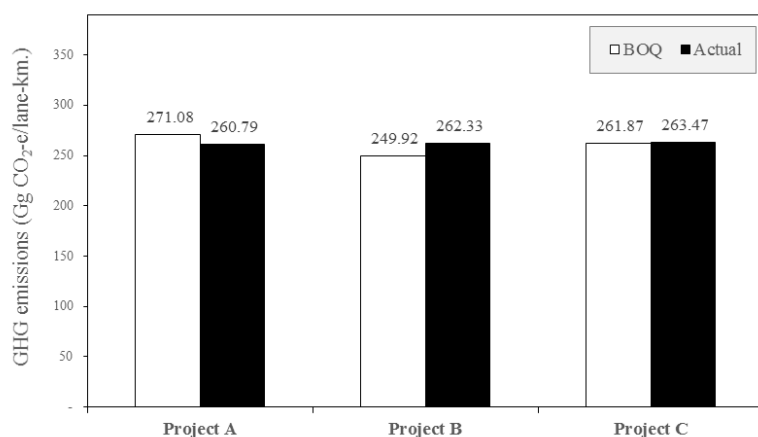


Fig. 5. GHG emissions from the three case studies

CONCLUSIONS

This paper presents the amount of GHG emissions for road construction projects. A comparison of results from the case studies between pre and post-construction phases. Project B were most different amount of GHG emissions 12,414.82 t CO₂-e/lane-km, which had the increased emissions by 5.0%. Secondly, project C had different emissions 1,605.56 t CO₂-e/lane-km, which increased emissions by 0.6%.

Contradictory with project A had different emissions 10,285.25 t CO₂-e/lane-km (decreased emissions by 3.8%). Considering in each stages of highway life cycle had the main cause of the different emissions was the fuel consumption by machinery at extraction and construction stages. While, overview of total amount emissions had the main cause were occur at the manufacturing stage, especially the surface course work were more than 80% of total emissions. Although, we have already adjust proportions of the machinery usage hours following in Equation 2 and Equation 3. This effect can just reduce for machinery manufacturing, but emissions from machinery usage were still the main cause of the projects. Another cause was some of the inconsistency of difference data sources, in particular day had work hours data from BOQ were 7 hrs/day, while the actual work data on the construction site were 8 hrs/day. Perhaps, that reason is more the energy consumptions and emissions at post-construction phase than at pre-construction phase. This reason made the assessment at post-construction phase will be appropriate way to assess for real emission in each projects. On the other hand, the assessment at pre-construction phase from BOQ data will be the reliable way, but must have improve some assumption of calculation for more data consistency, e.g., work hours per day of machinery usage etc. However, this research have purpose to comparison the efficiency of actual operations and the resources management on road construction project. Therefore, these data from different phase are the benefits and important also reflecting main causes of differently GHG emissions.

Table 3: The comparative emissions of the case studies between two different inventories.

		Extraction	Manufacturing	Construction	Total
Project A	BOQ	2.93	233.41	34.74	271.08
	Actual	2.77	232.12	25.89	260.79
	Diff.	-5.2%	-0.6%	-25.5%	-3.8%
Project B	BOQ	2.85	207.09	39.98	249.92
	Actual	4.12	206.95	51.26	262.33
	Diff.	44.6%	-0.1%	28.2%	5.0%
Project C	BOQ	6.33	214.80	40.73	261.87
	Actual	8.51	200.00	54.96	263.47
	Diff.	34.4%	-6.9%	34.9%	0.6%

Note: Emissions in Gg CO₂-e/lane-km.

The difference emissions of machinery usage is present the important of machinery cost management, it may be conducted to high or low emissions. As the results, project A had early complete project in contract four months, it reflects the better resources management. While, project C had accelerating at the end of period time for complete project by the due date of contract, it reflects the resources management in the secondary role. On the other hand, project B had delayed time and must have more accelerating for complete project by the new due date of contract, that is the worst management than the other projects and also may be the most GHG emissions project. This research proposed a new calculation method for emissions of machinery usage based on the proportion of usage hours and useful life. The operations monitoring on construction projects can be demonstrated the performance of the resources management in each of projects. The stakeholder should be awareness and attention of two important things, i.e., first thing is the machinery usage management for more performance; and the next thing is the design materials alternatives in pavement work

for more performance, because there are the significant effects to GHG emissions if we want to reduce the serious emissions. However, this proposed method has some limitations are that it must be implemented on the on-going projects, and it requires pre-qualification data which are confidential information to owners only.

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DEVELOPING AN EARLY DESIGN STAGE EMBODIED CARBON PREDICTION MODEL: A CASE STUDY

Michele Victoria¹, Srinath Perera and Alan Davies

Department of Architecture and Built Environment, Northumbria University, Newcastle upon Tyne, UK

The focus of carbon management has shifted from operational carbon towards Embodied Carbon (EC) as a result of zero carbon agenda. Even though effort is made to quantify EC in detail design stage and choose the best solution for design there is no such approaches in managing EC during early stages of the design. The reason for this is lack of sufficient design information to quantify EC at early design stages. Hence, this research intends to fill that gap by using a unique approach of predicting EC by capturing the relationship between design and morphological parameters (such as plan shape, storey height, no. of storeys, finishes quality, services quality, etc.) and EC. Some building elements can be considered as 'carbon hotspots' (carbon intensive). Since carbon and cost are known to be the currencies of sustainable construction projects, the aim of the study is to develop a decision support system to optimise design in terms of carbon and cost during early stages of design. The aim is to be achieved by developing a database of elemental (NRM compliant) EC and cost (using Hutchins UK Building Blackbook and other data sources) of sample office buildings in the UK and identifying the correlations of EC and cost with design parameters. Consequently, regression models will be derived as the key component for the DSS development. This paper presents a detailed literature review of EC and EC estimating tools, a detailed discussion of the proposed research method and exemplar case study of an office building and EC and capital cost analysis of the building. The paper concludes with the identification of the carbon hotspots for the building (mainly, substructure, frame, upper floor and external walls) and compares it with published case studies while exploring the implications of the case study for the DSS to be developed.

Keywords: carbon hotspots, early stage design, embodied carbon, office building.

INTRODUCTION

Industrial revolution between 18th and 19th centuries is one of the main reasons for significant rise in the global mean temperature. As a result, climate started to change radically due to excessive presence of heat trapping gases like carbon dioxide in the atmosphere. Consequently, economic, environmental and social conditions of the world regions started to be affected. Especially, poor nations are reported to be suffering more due to insufficient financial means to safeguard themselves against climate impacts (Intergovernmental Panel on Climate Change, 2012, 2013; Stern, 2007). Hence, developed regions came on board to combat climate change or to reduce greenhouse gas emissions by policy formulation and commitments to international climate change agreements like Kyoto Protocol (United Nations, 1998). More importantly, the UK government has set more stringent national targets to meet the 2050 emission reduction target of Kyoto Protocol through UK Climate Change

¹ michele.f.victoria@northumbria.ac.uk

Act 2008. Furthermore, action plans are also continually reviewed to suite the projected climate change and reported to the government periodically by Committee on Climate Change. Mainly, carbon control in the building sector is identified as one of the significant action plans to reach the target because building sector is one of the major exploiters of resources and energy (Committee on Climate Change, 2013). However, in the action plans more focus was given to reduce carbon emissions during the operation of the building (known as 'operational carbon') which contributed to nearly 70-80% of total emissions from buildings until the zero carbon agenda for buildings was introduced. Eventually, zero carbon agenda implicitly emphasise the need to control the other component of the building sector emissions, namely 'embodied carbon'. EC is driven by process and affected by the supply chain, thus, hard to manage. However, dual currency approach of clients and consultants highlight the importance of EC estimating and management. Therefore, it can be expected that the knowledge of cost and carbon relationship will become a valuable asset for the construction practices in the near future which makes the study outcomes significant.

LITERATURE REVIEW

Carbon in buildings

There are two types of carbon emissions in buildings namely: operational carbon and embodied carbon (also known as capital carbon). The contribution of the two in total emissions varies depending on the type of the building and design variables. The relationship between operational and embodied carbon was studied by Ibn-Mohammed, Greenough, Taylor, Ozawa-Meida, and Acquaye (2013) by drawing evidence from various studies from different countries. Accordingly, the findings of the above study suggested that there is no static relationship and it often varies. However, generally, operational carbon emissions are much higher than embodied emissions in most of the building types while there are exceptions like warehouses (See, RICS, 2014).

Operational carbon in buildings

RICS (2014) defines operational carbon in buildings as emissions related to energy consumption during the operation of the building. These emissions include both regulated loads (e.g. heating, cooling, ventilation and lighting) and unregulated/plug loads (e.g. ICT equipment, cooking and refrigeration appliances). Building Regulation Part L has provisions of controlling regulated operational carbon in buildings as the unregulated emissions are entirely depended on occupants' behaviour.

As per the Part L of the Building Regulations, the operational emissions or the Target CO₂ Emission Rate (TER) for the notional building design is calculated using either Standard Assessment Procedure (SAP), or Simplified Building Energy Model (SBEM) or other approved software tools where actual Building CO₂ Emission Rate (BER) should be less than the TER for the building design to be approved. The operational emissions are expressed in mass of CO₂ emitted per year per square meter of usable floor area of the building (kg/m²/year). Although the benchmarks are set for the BER, there is a performance gap between predicted emission levels and actual emission levels (Pan and Garmston, 2012; UK-GBC, 2008, 2014) which is a serious issue to be addressed at the earliest possible in order to meet 2050 target.

Conceptually, in a zero carbon building operational carbon (regulated energy use) will be zero whereas the remaining component to be controlled becomes the embodied carbon in buildings. Further, Ibn-Mohammed *et al.* (2013) also stress that serious attention needs to be given on embodied carbon during design decision making.

Embodied carbon in buildings

Ibn-Mohammed *et al.* (2013) reviewed various interpretations of embodied energy and carbon from various studies. The review demonstrated variations in the definitions in terms of the terminologies used and the scope of the emissions considered.

However, the definition proposed by Hammond and Jones (2008) can be regarded as acceptable as they are the producers of the very first inventory of embodied carbon and energy which drives most of the embodied carbon researches. Hammond and Jones (2011) revised the older definition (Hammond and Jones, 2008) and define embodied carbon as “the sum of fuel related carbon emissions and process related carbon emissions”. Authors did not confine the scope of emissions in the definition as embodied carbon can be calculated from cradle (earth)-to-gate (factory gate), cradle-to-site, cradle-to-end of construction, cradle-to-grave, or even cradle-to-cradle (includes recycle, reuse etc.) depending on the scope of data available. This is called as the system boundary of embodied carbon calculations. Few scholars noted that many embodied carbon datasets available are cradle-to-gate due to difficulties in capturing data (Hammond and Jones, 2011; Sansom and Pope, 2012). However, transport of materials to site adds significantly to total embodied carbon emission for some materials which has less embodied emissions in other phases (Hammond and Jones, 2008). Furthermore, lesser transport distance not necessarily means lesser carbon emissions as mode of transport and type of fuel also plays a significant role in addition to distance of travel (RICS, 2014; Sundarakani, de Souza, Goh, Wagner, and Manikandan, 2010).

Managing embodied carbon requires great deal of understanding and attention to detail. In a construction project, most (around 70 - 85%) of the cost is committed during design stage of the project (Asiedu and Gu, 1998) and so as with the carbon as both carbon and cost depends on the same factors like, material quantity, transport, construction method and so on. On the other hand, as more cost and carbon is committed into the project, the reduction potential decreases increasingly as possible design solutions are constrained by previous design decisions. Then, during construction phase the reduction potential can be regarded as nearly zero unless there is a design change (see Figure 5). Therefore, any measures to minimise the embodied carbon or cost in buildings has to be taken at very early stages of design due to the fact that reduction potential diminishes as design progresses (RICS, 2014). Further, the design becomes static as the project progresses and changing the design at a later stage will result in loss of time and money.

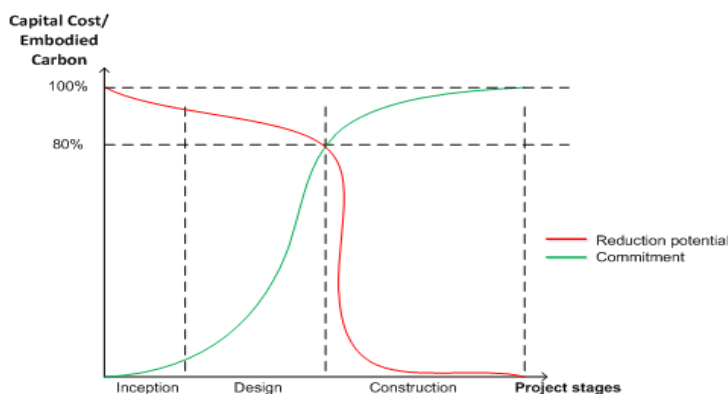


Figure 5: Behavioural pattern of Embodied Carbon and Capital Cost over project stages After, RICS (2014)

Furthermore, RICS (2014) states that investigating embodied carbon emissions in different types of buildings is a completely new research avenue. Evidently, there are limited regulatory standards or academic researches to aid decision making at early stages of projects. In addition to that intense calculations involved in embodied carbon measurement also makes it complex and undesirable (Ibn-Mohammed *et al.*, 2013). Nevertheless, this research identified carbon hotspots in buildings as an ideal way of dealing with this issue; according to 80:20 Pareto rule, it can be assumed that 80% of emissions are to be coming from 20% of elements. However, that 20% of elements (carbon hotspots) are not yet firmly configured.

RICS (2014) defines 'Carbon hotspots' as the carbon significant aspect of the project. It not necessarily means the carbon intensive elements but also the elements where measurement data is easily available and reduction is possible. These carbon hotspots may vary from project to project depending on the type of the building. Generally, foundations, frame, roof, walls, and floors are considered as carbon hotspots. Furthermore, due to the complex nature of measurements of services in early design stages and lower reduction potential among others make building services less significant carbon hotspot even though it might contribute 10-25% of total embodied carbon (Hitchin, 2013; RICS, 2014). However, a study found that cladding finishes and services are to be the biggest component of recurring carbon emissions of an office building (Cole and Kernan, 1996). Hence, services and finishes cannot be disregarded when taking initial design decision as the contribution is significant. Therefore, it is important that the indication of likely embodied carbon of building services and finishes are revealed at the early stages of design to understand the carbon accountability of the project.

Subsequently, the study identified and analysed some of the embodied carbon case study findings of office buildings in the UK (Clark, 2013; Halcrow Yolles, 2010a; 2010b, WRAP; Sturgis Associates, 2010). It was noticed that the element classification differs from one study to the other (for example, NRM, SMM/BCIS - older version, British Council of Offices 2011, some studies did not follow any standards) makes it difficult to compare. Further, Clark (2013) also observed that findings of two different experienced consultants for the same building greatly differed. Dixit, Fernández-Solís, Lavy, and Culp (2010) identified a list of factors that affects the embodied carbon measurements. However, diversity of assumptions, source of embodied carbon factor and variation in methodology adopted (Clark, 2013) can be regarded as the most significant factors for the reported variations. Furthermore, element classification also highly alters the findings. Especially, analysis of embodied carbon in building services remains as a mystery due to lack of comprehensive published dataset. Furthermore, most studies lack elaboration on the methodology which questions the validity and applicability of the findings.

Eventually, this study attempts to eliminate the drawbacks identified in previous studies and develop a robust hierarchy of carbon hotspots in office buildings in the UK. The study follows NRM element classification, the standard which is in practice at the moment in the UK and makes it comparable with cost estimates. From that the study proposes a novel technique of predicting embodied carbon at early design stages based on well-established relationship of cost and design variables (Ashworth, 2010; Seeley, 1996) as both capital cost and EC depends on the same factors. Accordingly, the research tries to capture building morphological parameters and quality parameters (plan shape, storey height, total height, finishes quality, service quality and the like)

related to the carbon hotspots and modelling them into a mathematical equation to capture carbon at early design stage.

Finally, the research idea can be presented in a conceptual regression model as follows:

$$\text{Carbon Factor} \left[\frac{\text{Carbon}}{\text{m}^2} \right] \propto \text{Morphology Parametrs } (M_P)$$

$$\text{Carbon Factor} \left[\frac{\text{Carbon}}{\text{m}^2} \right] = f(M_P, L_S, L_F)$$

$$\text{Carbon Factor} \left[\frac{\text{Carbon}}{\text{m}^2} \right] \propto \text{Level of Sevices } (L_S)$$

$$\text{Carbon Factor} \left[\frac{\text{Carbon}}{\text{m}^2} \right] \propto \text{Level of Finishes } (L_F)$$

$$\text{Carbon Factor} \left[\frac{\text{Carbon}}{\text{m}^2} \right] = a \left(\frac{\text{Wall}}{\text{Floor}} \right) + b(\text{Storey Height}) + c(\text{Total Height}) + \dots$$

$$\dots + \text{Service Index} + \text{Finshes Index} + k$$

(a, b, c...k = regression)

Yet, it is useful to review the existing early stage carbon prediction models and underlying methodologies so that the strengths and weaknesses of the tools can be identified and issues can be addressed during the development of the decision support system.

Carbon Estimating Tools

Carbon estimating tools are in abundance and access is either free or licensed. Even though all tools tend to perform the same function there are differences in input information, system boundary, outputs, methodology and data sources. The study identified some freely accessible early stage carbon estimating tools include: Construction Carbon Calculator developed by Build Carbon Neutral; Embodied CO₂ Estimator developed by Phlorum (Phlorum, 2011), in collaboration with the University of Brighton; Green Footstep developed by Rocky Mountain Institute (Rocky Mountain Institute 2009); Building Carbon Calculator developed by University of Minnesota (University of Minnesota, 2014); and Steel Construction Embodied Carbon Tool developed by TATA steel (TATA Steel, 2014). First three are web based tools whereas Building Carbon Calculator is an excel based tool and Steel Construction Embodied Carbon Tool is a computer based tool. Each tool has its own limitations. Major limitation is to be the applicability of the tools which depends on the context and type of the building. This limitation becomes unavoidable for small scale projects with limited funds. Another common factor among these tools is the system boundary. Most of the tools cover cradle to construction (excluding transport) system boundary while this is not clearly stated in few identified tools which is a drawback.

In addition to those there are tools that estimate carbon in detailed design stages such as Carbon calculator for construction projects (an excel tool developed by Environment Agency), The Green Guide Calculator (A web based tool developed by BRE in compliance with 'The Green Guide to Specification'), Interoperable Carbon Information Modelling (iCIM - a tool developed in a BIM platform by "OpenBIM"), Sturgis Carbon Profile Model (model developed by Sturgis which combines both operational and embodied carbon into one unit and proposed a methodology to measure life cycle carbon of a building in kgCO₂/m²/year) are to name few. In summary, it is clear that each tool is different and do have limitations. Further, among early stage carbon estimating tools cost is rarely incorporated.

Nevertheless, cost also changes along with embodied carbon when design variables change. Further, construction clients are becoming more conscious about dual currency, cost and carbon, in building development. Therefore, it is ideal to club both carbon and cost in one tool so that decision making is made easy with cost and carbon information that can be easily generated during early design stages. The shortfalls like differing element classification of previous studies and lack of cost consideration among the identified early stage carbon estimating tools justify the case for the study. Therefore, this study capitalises existing limitations in the literature and current tools and tries to develop a decision support system (DSS) that predicts embodied carbon and capital cost of early stage designs based on the correlations between design variables, and carbon and cost.

METHODOLOGY

Primary source of data for this research will be building data and published data. Building data (Bills of Quantities and architectural drawings) is obtained from consultancy organisations. Sample of 30 buildings' data are expected to be collected to build the principal database for the research.

Firstly, embodied carbon will be calculated for each building manually with excel aided functions and carbon intensive elements will be analysed. The major data sources to perform this task would be Inventory of Carbon and energy (ICE) version 2.0, UK Building Blackbook and where necessary manufacturer's data. Then, hypothesis will be test to understand whether there is a significant relationship between different morphological (i.e. plan shape, building height etc.) and quality parameters (services quality and finishes quality) of the building with that of the respective carbon emissions and cost. Subsequently, correlation coefficient will be calculated as it is an appropriate measure of the strength and direction of the linear correlation between two numerical variables. Finally, algorithms will be developed with multiple variables to predict carbon and cost at early design stages with the aid of SPSS software and significance of each identified design parameters will be investigated subsequently during modelling and a best predictive model (algorithm) will be derived from the database of processed building data.

However, this paper presents a case study of an office building as an exemplar due to the ongoing nature of the research. The case study involves cost and carbon estimating of the building using detailed cost plan of the building and the data sources mentioned above. The cost and carbon estimating follows the conventional cost estimating process (Pre-tender estimate pricing) and both unit cost and unit carbon data are obtained from the same source to maintain consistency and comparability.

FINDINGS

Case study

Office A

- Gross Internal Floor Area : 33,663 m²
- Net Internal Area : 22,634 m²
- Number of Floors : Above Ground- 18, Below Ground - 2
- Brief Description : Raft foundation with concrete core walls, hybrid framed building comprising flat roof, curtain walling system and aluminium cladding, brick, block, dry lined partitions and glazed units, moderate finishes and highly sophisticated services including mechanical,

electrical and plumbing as well as specialised services like Building Management System (BMS).

- Capital cost : £23,131,452.04
- Embodied carbon : 23,769,592.57 kgCO₂

Figure 6 and Table 5 below presents the findings of the study in compliance with NRM element classification.

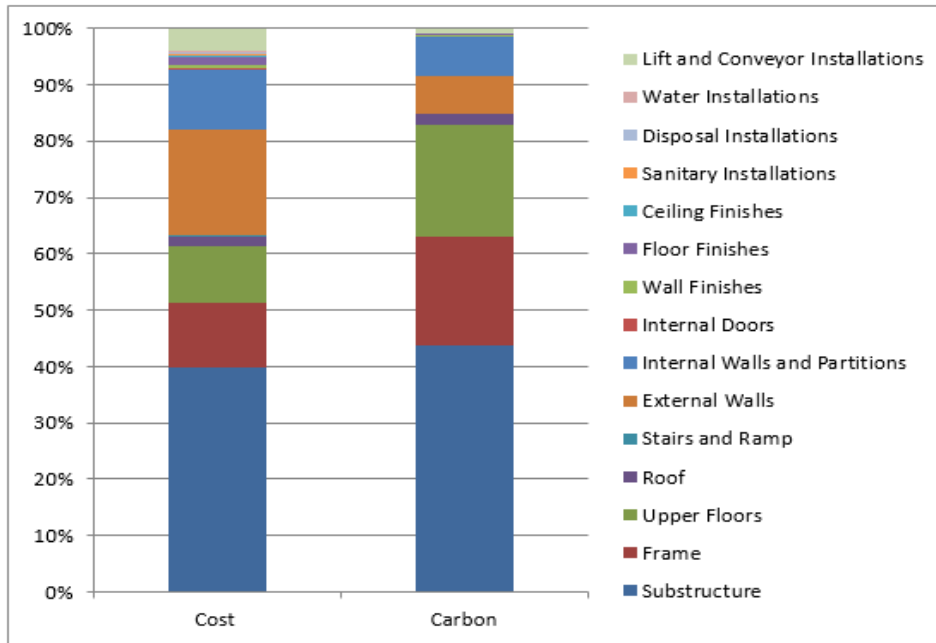


Figure 6: Elemental Embodied carbon and cost profile of case study office building

Table 5: Hierarchy of carbon and cost intensive elements- Findings of the case study

Element	Cost	Carbon
Superstructure	52.89%	54.66%
Substructure	39.70%	43.79%
Services ¹	4.91%	0.93%
Internal Finishes	2.20%	0.57%
Fittings & Furnishings	0.30%	0.05%



Findings suggest that there is a close relationship between cost and carbon. In terms of both carbon and cost the intensive element hierarchy remains the same. This knowledge can lead to effective decision making in early stages of design. However, this finding is based on one case study and more case studies to be conducted in the future. Further, external work is not included in the cost and carbon estimates as it depends on client's special needs, landscape and location of site, thus, tends to have a wider range irrespective of the scale of project.

Despite the benefits that the study yields there are also various problems encountered during this process. Major issue was carbon and cost calculations are performed from detailed cost plans of the office building, thus, some items are combined and measure in 'Item' or 'Lump sum' which makes it difficult to analyse the lowest level of specifications and details. Then, the UK Building Blackbook does not contain data for all the items, in which case a closer item specification is matched to obtain the carbon and cost factors. More importantly, building services embodied carbon data are

limited² due to the sophisticated nature of the element as mentioned by RICS (2014) and Hitchin (2013). Hence, calculations are not holistic and some of the items could not be included in the quantification due to lack of sufficient information or published data. However, care was taken to include most of the significant items. Moreover, author presumes that under representation of building services among other elements in terms of embodied carbon may be due to lack of published data. Further, the study points out the importance of embodied carbon data of building services and it is envisaged that the need for it will rise in the future.

Comparison with other studies

Table 6 presents and compares the findings of the study with other studies. Findings of other studies are altered to be aligned with the element classification of the study (NRM compliant classification). Accordingly, substructure and superstructure together are to contribute to more than 80%, in line with the findings of most of the studies. Services element demonstrates a huge variation among presented studies ranging from 0.93% - 25%. This is due to difference in the scope of analysis of services element and the methodology employed. The study had limitations in EC quantification of major services like electrical installations, gas installations, communication installations, fire and lighting protection installation and various other specialist installations due to lack of EC data. As a result, EC of building services of the study is comparatively very low. Furthermore, many studies do not clarify what constitutes the services element in the analysis which becomes a drawback for comparisons. Moreover, when EC of building services items are closed analysed it appears to be very small resulting in less contribution. If that is the case, then as RICS (2014) claims, services can be disregarded during early stage decision making.

Table 6: Comparison of the case study findings with other studies

	The Study	Halcrow & Yolles (Average of 3 case studies)	Sturgis Associates	WRAP	Davis Langdon from Clark (2013)
Substructure	43.79%	89% (some elements are combined)	25%	18.3%	Structure - 45%-85%, Facade - 5%-25%
Superstructure	54.66%		56%	58.24%	
Internal Finishes	0.57%	Not given	Fit-out (shell & core) - 8%, Fit-out (Cat B) - 8%	8.619%	4%-25% (Internal walls included)
Fittings & Furnishings	0.05%			Not given	
Services	0.93%	3%		11.96%	2-25%
Others		8% (External works)	4% (Waste)	2.9% (External works)	

However, the findings are based on single case study and the project is yet to progress with more case studies. Therefore, the study does not draw any conclusions regarding building services EC.

CONCLUSIONS

Increasing significance of embodied carbon in buildings and difficulty in prediction during early stages of design due to very little design information became the driver for the study. Eventually, analysis of relationship between embodied carbon and

² Except for that are available in Blackbook - plumbing, drainage, electrical and transport systems. Especially electrical data are for two storey housing installation which cannot be used in the context, which is why electrical installation is not presented in **Error! Reference source not found.**

design variables provided the direction for the study as some of the building elements are to be carbon critical (hotspots). Therefore, modelling design variables related to carbon hotspots tends to make the predictive model simple and closer to the actual figure which is also supported by 80:20 Pareto rule. However, it was also noticed that there are many studies that analysed carbon hotspots and often reflected inconsistency in findings. Subsequently, a standard method of presenting building elements was adopted in the study which is NRM compliant element classification, making it easier for interpretations and re-use of results. Consequently, case study of an office building was presented and the findings were compared with other studies. Substructure and superstructure (especially, frame, upper floor and external walls) are identified to be the carbon hotspots being responsible for more than 80% of embodied carbon emissions. It was also noticed that there is a huge variation in embodied carbon figures of building services among studies due to the variation in the scope of analysis which is not transparent. Findings of the case study demonstrated a similar hierarchy of elements in embodied carbon and cost profile of the building which knowledge is mostly missing in other studies. This knowledge will become crucial for designers to economically achieve 2050 emission reductions target of the Kyoto Protocol.

FUTURE WORK

The project will conduct more building case studies (approximately 30) and analyse the relationship between carbon and cost. Further, early stage carbon and cost models will be derived based on design variables. The derived models will lay the foundation for the development of the decision support system to optimise design in terms of carbon and cost during early stages of design.

CONTRIBUTION TO THE KNOWLEDGE

The research contributes to the knowledge by: identifying carbon hotspots in office buildings; capturing the relationship between EC and design variables; showcasing capital cost and EC relationships; and developing a DSS to optimise design during early stages.

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EXTENDING THE CLEAN DEVELOPMENT MECHANISM CONCEPT TO BUILDING PROJECTS

Nathan Kibwami¹ and Apollo Tutesigensi

Institute for Resilient Infrastructure, School of Civil Engineering, University of Leeds, Leeds, LS2 9JT, UK

The Clean Development Mechanism (CDM) is a global scheme intended to provide a flexible way to comply with carbon emissions reduction commitments through emissions trading. In this scheme, countries can purchase certified emission reduction (CER) credits, each equivalent to one tonne of avoided emissions, to meet part of their emission reduction commitments. The CER credits are generated from emission reduction activities that are undertaken in developing countries. Although the CDM has benefited several sectors, the building sector hitherto accounts for a meagre proportion of the globally registered CDM initiatives. However, recent research suggests that there is potential in using the CDM concept to address carbon emissions associated with buildings. Further to this suggestion, this paper presents a demonstration of how the CDM concept could be applied to building projects in a developing country, Uganda. A two-bedroom residential house was considered as the unit of analysis and carbon emissions associated with constructing its walls were derived, considering materials, plant, and workforce used. Two options for the house were considered: a baseline (i.e. constructed using typical materials, plant, and labour) and green alternative (i.e. constructed using provisions to reduce carbon emissions). The difference in carbon emissions in the two options was found to constitute a basis for a CDM whose structure is presented and discussed in this paper. Considering a bottom-up projection regarding construction of residential houses in Uganda, the findings show that using the CDM concept, carbon emissions reduction of over 200 ktCO₂ could be achieved in a period of 10 years. These figures were found comparable with prevailing CDM initiatives which are not associated with buildings. The overall findings indicated that extending the CDM concept to building projects is plausible and could promote market-based mechanisms of enhancing sustainable construction.

Keywords: carbon emissions, clean development mechanism, sustainable construction.

INTRODUCTION

The intervention of national and international emissions reduction regulatory regimes suggests that global warming is recognised as a global threat (UK Climate Change Act 2008; WRI/WBCSD 2005; Kyoto Protocol 1998; UNFCCC 1992). Global warming is primarily caused by increasing concentrations of greenhouse gases (e.g. carbon dioxide, methane, nitrous oxide, etc.) in the atmosphere, most of which arise from human activities such as burning of fossil fuels and manufacture of materials like cement (Hegerl *et al.* 2007; Worrell *et al.* 2001). For such a global threat, attempts to address it have, ipso facto, taken the form of global initiatives. One of such acclaimed

¹ cnnk@leeds.ac.uk

global initiatives is the Clean Development Mechanism (CDM), which, although has appealed to several sectors, its popularity in the building sector is hitherto dismal.

The principle and aims of the CDM concept are quite straight forward. CDMs were established under Article 12 of the Kyoto Protocol (1998) – an international treaty to reduce greenhouse gas (GHG) emissions– to provide flexible market-based mechanisms of reducing GHGs by emissions trading. For industrialised countries that are signatory to the Kyoto Protocol (1998), they had to reduce their emissions by 5% of 1990 levels during the first commitment period of 2008 to 2012. The second commitment period, as adopted in the ‘Doha amendment to the Kyoto protocol’, stipulated another 8-year commitment period (2013 to 2020) to reduce emissions by 18% below those of 1990 (UNFCCC 2013a). In CDM initiatives, industrialised countries with emission-reduction commitments can purchase certified emissions reduction (CER) credits, each equivalent to one tonne of emissions avoided. The purchased CER credits can then be used to offset emission reduction targets. However, the CER credits must have been generated from emission-reduction activities (e.g. planting of trees, renewable energy projects, energy efficiency measures etc.) undertaken in developing countries. Thus developing countries benefit from the revenue resulting from the sale of CER credits, and other benefits such as employment, that the emission-reduction activity can accrue. So, the aim of CDM is dual: enabling industrialised countries to meet emission reduction targets, while facilitating developing countries to achieve sustainable development (Kyoto Protocol 1998).

Although buildings are both energy and carbon-intensive, they have not yet attracted adequate attention from CDMs. The building sector globally consumes up to 40% of the final energy and releases 30% of the annual global emissions (WBCSD 2012; UNEP 2009). If the energy consumed during the construction phase is considered, buildings account for more than 50% of the global energy consumption (WBCSD 2012). However, by February 2006, nearly a year after the CDM concept came into force, less than 5% of the total registered CDMs were related to buildings, with none in pipeline for registration (Novikova *et al.* 2006). By May 2008, of the 3000 CDMs in pipeline then, only six were related to buildings (Cheng *et al.* 2008). Even in countries like China, which host the largest share of CDMs globally, the building sector is still not a popular attraction for CDMs (Zhou *et al.* 2013). Moreover, for the few registered building-related CDMs, they are related to the operation phase of buildings and none addresses the construction phase of buildings. Unsurprisingly, current information available from the CDM repository shows that, for the designated fifteen CDM sectoral scopes, there are currently no registered CDMs under the ‘Construction sector’ scope (UNFCCC 2015). As such, the mystery surrounding the paucity of building-related CDMs indeed deserves investigation.

Recent research has endeavoured to explore various aspects pertaining to CDM activities related to buildings. In most of the cases (UNEP 2009; Cheng *et al.* 2008; Hinostroza *et al.* 2007; Novikova *et al.* 2006) discussions have dwelt on underscoring the barriers hindering buildings to benefit from CDM; these include: transaction costs outweigh economic benefits, buildings are small-scale in nature, buildings are both fragmented and geographically spread, lack of appropriate methodologies, and lack of reference baselines. Some researchers (see Mok *et al.* 2014; Zhou *et al.* 2013) have taken a step further to conduct empirical research with the objectives of, among others, suggesting potential solutions to such barriers. Meanwhile, other studies (e.g. Kibwami and Tutesigensi 2014a) claim that CDMs could promote sustainable

construction in developing countries. However, there are no studies that provide a demonstration of how the CDM concept can be applied to buildings and more so, elucidate how building-related CDMs could promote sustainable construction. To fill this gap, this paper presents a demonstration of how the CDM concept can be applied to building projects in the context of Uganda.

Since CDMs must be hosted by developing countries (Kyoto Protocol 1998, Paragraph 3a), it is reasonable to consider the CDM concept in the context of Uganda. Uganda is a developing country (UNCTAD 2011) that has hosted several CDM initiatives (Olsen 2006), and it was the first in Africa to undertake a forestry CDM project (World Bank 2009). However, the global scarcity of CDMs in the building sector also reflects on Uganda, as the country has no CDMs related to the building sector. Yet, the country's efforts of increasing the rate of housing construction (Kalema and Kayiira 2008) in order to counter the persistent housing deficit (The New Vision 2008) affects the environment. It is widely acknowledged that construction is associated with activities (material manufacture, transportation, equipment use and so forth) that lead to carbon emissions (UNEP 2009; Cole 1998). Therefore, if a developing country like Uganda is to pursue a low-carbon path to development, which in this case implies shrinking the housing deficit sustainably, consideration of CDMs related to buildings is important.

METHODOLOGY

In order to demonstrate how the CDM concept can be applied to building projects, some considerations were made upon which emissions calculations were based.

Considerations

A typical dwelling unit (see Table 1), whose details were obtained from an engineering firm, was assumed to be constructed in Kampala, the capital city. A model suggested in Kibwami and Tutesigensi (2014b) was used as guidance in computing the resulting carbon emissions. Two options of constructing the dwelling's walls were considered: a baseline constructed using typical materials, plant/equipment, and workforce; and a 'green' alternative constructed using provisions to reduce carbon emissions. Thus for the entire dwelling unit, potential emission reductions were associated with construction of its walls only, similar to recent proposals by UNFCCC (2013b). Energy sources were diesel, biomass, heavy fuel oil, biodiesel, and grid electricity, since these are either predominantly used, or have a great potential (UBOS 2013). The emission-factors (see Table 2) were taken from UNFCCC (2010) which is a country-related source and thus considered to be representative of the context. The disaggregation factors referred to in the referenced model were taken as the various proportions of energy required for the baseline and alternative options (see Table 3). The proportions for the baseline option were based on typical energy use in Uganda. For instance, energy used in the cement industry comes from diesel, biomass, heavy fuel oil, and grid electricity; in some factories, biomass accounts for 30% of the total energy used (Lafarge 2012). The alternative option was based on the goal of Uganda's renewable energy policy: dependence on 61% renewable energy by 2017, with biofuel blends of up to 20% in the transport sector (The Republic of Uganda 2007). Therefore, for manufacture of materials in the alternative option, 60% of the energy was assumed to be sourced from non-fossil renewable energy, whereas 20% biofuel blend was assumed in all transportation activities. The overall emissions computed arose from manufacture and transportation of materials, and transportation of workforce. Emissions from equipment-use were not

considered since the activity of constructing the walls was assumed to be entirely carried out by human workforce without need for powered equipment.

Table 1: Information about the house

Parameter	Description
Building type	Typical two-bedroom residential house
Construction type	Traditional: masonry burnt mud bricks
Floor to wall-plate height	3m
Number of bedrooms	2No.
Number of floors	1No.
Internal floor area	103m ²
Total wall area	223m ²
Wall width (un-plastered)	0.107m (based on 228x 107 x 69mm bricks)*
Openings areas: Doors	21m ²
Windows	24m ²
Roof type and structure	Corrugated iron sheets on Timber roof truss structure
Total Cement required (walling only)	2.23Tons (assuming 0.01tons per m ² , stretcher bond)*
Total bricks required (walling only)	11,147 bricks (50 bricks per m ²)
Total sand required (walling only)	1 trip, 6-tonne truck
Water	excluded in the analysis

*source: UNFCCC (2013b)

Table 2: Emission factors for common energy sources in the context

Fuel/energy source	Emissions factor*	Conversion to MJ 1kWh=3.6MJ
Diesel (100% mineral diesel) for vehicles	0.545 kgCO ₂ /km	N/A
Diesel (electricity)	0.68 KgCO ₂ /kWh	0.189 KgCO ₂ /MJ
Heavy fuel oil (HFO) for electricity	0.71 KgCO ₂ /kWh	0.197 KgCO ₂ /MJ
Biomass	0	N/A
Grid electricity (diesel, HFO, and Hydroelectricity mix)	0.14 kgCO ₂ /kWh	0.039 KgCO ₂ /MJ

source: UNFCCC (2010)

Table 3: Proportion of energy used

Energy sources	Material (cement) manufacture		Transportation (material or workforce)	
	Base line	Alternative	Base line	Alternative
Diesel	0.35	0.10	1.00	0.80
Non-fossil	0.30	0.60	0.00	0.20
Heavy fuel oil	0.05	0.00	N/A	N/A
Electricity	0.30	0.30	N/A	N/A
Total	1.00	1.00	1.00	1.00

Assumptions regarding emissions from manufacture (and transportation) of materials, and transportation of workforce were posed. For cement manufacture, which causes both energy (46%) and process-related (54%) emissions, the energy requirement was taken as 4.9MJ/kg (Worrell *et al.* 2001: 321). The country's two largest cement producers 'Hima' (in the West) and 'Tororo' (in the East) are located approximately 350 km and 209 km respectively from the capital city (based on Google Maps); a 560 km average roundtrip was considered, based on a 6-ton diesel truck (UNFCCC 2010). According to typical brick manufacturing practices in Uganda (i.e. wood-fired kilns), the associated emissions were cautiously taken as zero, similar to Pooliyadda and Dias (2005). Also, no production emissions were considered for sand, as it is a naturally

occurring material that is usually unprocessed, though requires transportation. Bricks and sand are usually sourced not very far from construction sites; a 50 km roundtrip distance was considered in each case, based on a 6-ton diesel truck. For emissions from transportation of workforce, a typical 14-passenger public transportation vehicle was considered. Similar to Cole (1998), no vehicle-sharing was assumed and thus each person travelled separately. Emissions per person per unit distance were obtained as: $0.545 \text{ kgCO}_2/\text{km} \div 14 = 0.0390 \text{ kgCO}_2$. Each person was assumed to travel a 20 km roundtrip per-day and thus emissions per person per day were: $0.039 \times 20 = 0.780 \text{ kgCO}_2$. A total workforce of four people was presumed: two masons, each with an assistant. Since a mason can construct $3.17 \text{ m}^2/\text{day}$ (Nalumansi and Mwesigye 2011), yet 223 m^2 of walls were to be constructed, the total construction duration was obtained as: $223 \text{ m}^2 \div 3.17 \text{ m}^2/\text{day} \div 2 = 35 \text{ days}$.

Calculation process

Emissions from manufacture of materials were computed by multiplying the total energy required to manufacture a unit of material, with the proportion of energy source used (see Table 3), with the emission factor of that energy source (see Table 2), and with the total quantity of material required (see Table 1). For instance, considering diesel-emissions in manufacturing cement, the baseline and alternative options were computed as: $4.9 \text{ MJ/Kg} \times 0.35 \times 0.189 \text{ kgCO}_2/\text{MJ} \times 2230 \text{ Kg} = 722 \text{ kgCO}_2$ and $4.9 \text{ MJ/Kg} \times 0.10 \times 0.189 \text{ kgCO}_2/\text{MJ} \times 2230 \text{ kg} = 207 \text{ kgCO}_2$, respectively (see Table 4). This calculation process was repeated for other energy sources, but with varying proportions (as per Table 3) of energy sources used.

Emissions from transporting materials were computed by multiplying the distance of transporting materials, with the proportion of energy source used, with the emissions emitted per unit distance for that energy source. Taking an example of transporting cement, the baseline and alternative options were computed as: $560 \text{ km} \times 1.00 \times 0.545 \text{ kgCO}_2/\text{km} = 305 \text{ kgCO}_2$ and $560 \text{ km} \times 0.80 \times 0.545 \text{ kgCO}_2/\text{km} = 244 \text{ kgCO}_2$, respectively (see Table 4). A similar calculation was applied for bricks and sand.

Emissions from transporting workforce were computed by multiplying the emissions per person per day, with the proportion of energy source used, with the total workforce required for the activity, with the total duration of the activity. Thus the baseline and alternative options were computed as: $0.780 \text{ kgCO}_2/\text{person/day} \times 1.00 \times 4 \text{ people} \times 35 \text{ days} = 110 \text{ kgCO}_2$ and $0.780 \text{ kgCO}_2/\text{person/day} \times 0.80 \times 4 \text{ people} \times 35 \text{ days} = 88 \text{ kgCO}_2$, respectively (see Table 4).

RESULTS AND DISCUSSIONS

Total emissions were considered based on the baseline and alternative scenarios. The implication of the results in relation to CDM was then discussed, followed by a presentation and discussion of the structure for the suggested CDM.

Amount of carbon emissions

The total emissions for the baseline and alternative options were 2550 kgCO_2 and 1834 kgCO_2 respectively (see Table 4), as further elaborated below.

Baseline

The total emissions for the baseline option represented $11 \text{ kgCO}_2/\text{m}^2$ of wall. With respect to manufacture, diesel contributed the most (75%) energy-related emissions. The amount of emissions was highly sensitive to heavy fuel oil, as it had the largest emission factor ($0.71 \text{ kgCO}_2/\text{kWh}$) amongst the fuels considered. Transportation

emissions (including materials and workforce) were 18% of the total emissions, implying that at 82%, the manufacture of materials contributed the most emissions. Such findings were not surprising since materials are known to constitute the biggest proportion of buildings' 'embodied' emissions (Chang *et al.* 2012: 794; Nässén *et al.* 2007: 1599; Scheuer *et al.* 2003: 1057).

Alternative

For the alternative option, the total emissions translated into 8 kg kgCO₂/m² of wall. This represented a reduction of 27% from the baseline option. The total energy-related emissions for manufacturing materials reduced from 957 kgCO₂ to 334 kgCO₂, representing a reduction of 65%. Workforce and material transportation emissions reduced by 20%. The alternative option therefore demonstrates how a certain construction practice can deviate from the baseline practices (e.g. by sourcing materials from manufacturers who use renewable energy, using biofuels in transporting materials and/or workforce, etc.) in order to reduce emissions. Such deeds demonstrate principles of attaining sustainable construction (Hill and Bowen 1997).

Table 4: Emissions from baseline and alternative options

		Baseline (kgCO ₂)	Alternative (kgCO ₂)
Manufacture of materials	Diesel	722	207
	Non-fossil	0	0
	Heavy Fuel Oil	108	0
	Electricity	127	127
	Non-fuel related emissions (54%)	1124	1124
	Subtotal	2081	1458
Transportation of materials	Cement	305	244
	Bricks	27	22
	Sand	27	22
	Subtotal	359	288
Transportation of workforce	Diesel-vehicle	110	88
Grand total		2550	1834

Implications of the results in relation to CDM

To address housing shortage in the capital city of Uganda, over 28,000 housing units have to be constructed annually within a duration of 10 years (UN-HABITAT 2010: 37). Assuming similar house units, for 2550 kgCO₂ per house, constructing walls of 28,000 houses would result into baseline emissions of 71 ktCO₂ (i.e. 2550 × 28000) annually. However, for the alternative 'greener' scenario, the annual emissions would be 51 ktCO₂ (i.e. 1834 × 28000), resulting in emission reductions of 20 ktCO₂ annually. If a duration of 10 years is considered, a total of 200 ktCO₂ would be avoided. These figures are comparable to those of CDMs that are not related to the building sector (see Table 6). Therefore, creating a CDM related to building projects (BP-CDM) is feasible, and considering the prevailing CDM modalities, it would be classified under small-scale CDM types which have emission reductions of up to 60 kt per year (UNFCCC 2014: 40). However, as demonstrated, the initiative would require covering a substantial geographical part of the country whereby in this case, the whole capital city would be considered as a single CDM project.

Table 5: Some registered CDMs in Uganda and extent of emission reduction

No.	Project title and registration date	Total reductions (tCO ₂ eq)	Annual Reductions (tCO ₂ eq)	Operation period (years)	Sector*
1	West Nile Electrification Project (WNEP); 10th February 2007	760,417	36,210	21	E/R
2	Uganda Nile Basin Reforestation Project No.3; 21st August 2009	111,798	5,564	20	A/R
3	Bugoye 13.0 MW Run-of-River Hydropower Project; 1st January 2011	510,740	51,074	10	E/R
4	Kachung Forest Project: Afforestation on Degraded Lands; 4th April 2011	547,373	24,702	20	A/R
5	Uganda Nile Basin Reforestation Project No. 4; 29th August 2011	79,395	3,969	20	A/R
6	Bujagali Hydropower Project; 7th October 2011	6,007,211	858,173	7	E/R
7	Mpererwe Landfill Gas Project; 20th January 2012	182,612	18,261	10	W/D
8	Buseruka Mini Hydro Power Plant; 21st May 2012	314,679	31,468	10	E/R
9	Namwasa Central Forest Reserve Reforestation Initiative; 31st January 2013	226,564	11,328	20	A/R

*E/R - Energy industries Renewable/non-renewable, A/R - Afforestation and Reforestation, W/D - Waste handling and Disposal, BP - Building Project. Source: (UNFCCC 2015)

Structure of the suggested CDM

Since building projects are usually geographically spread, a Programme of Activities (PoA) type of CDM would be appropriate. In PoA CDMs, several projects sharing similar goals can be registered as a single CDM (UNFCCC 2014). Since the project sites in a PoA can be located in various parts of a country (Fenhann and Hinostroza 2011), this can similarly relate to building projects. To manage the geographical spread of building projects, existing local government administrative authorities such as districts, can be used. Each district would be taken as a Component Project Activity (CPA) of the PoA. A CPA is technically defined as “a single measure, or a set of interrelated measures under a PoA, to reduce emissions or result in net removals, applied within a designated area.” (UNFCCC 2014: 22). In operationalising the BP-CDM, the CPAs would keep up-to-date official records (e.g. of emission factors) specific to the geographical region concerned. Upon building permit applications, baseline emissions would be assessed. The investors (e.g. clients, contractors) who opt in for the BP-CDM can then be advised of ‘greener’ options such as which manufacturers to buy materials from. On completing construction, a reassessment could be done, and the extent of deviations from the baseline revealed. If positive (i.e. emissions reduced), a verification can be carried out to assess where the emission reductions were achieved (e.g. whether manufacturer, contractor, client or workforce) in order to apportion incentives appropriately. The BP-CDM can be structured into three levels (see Figure 1), each with various actors and responsibilities.

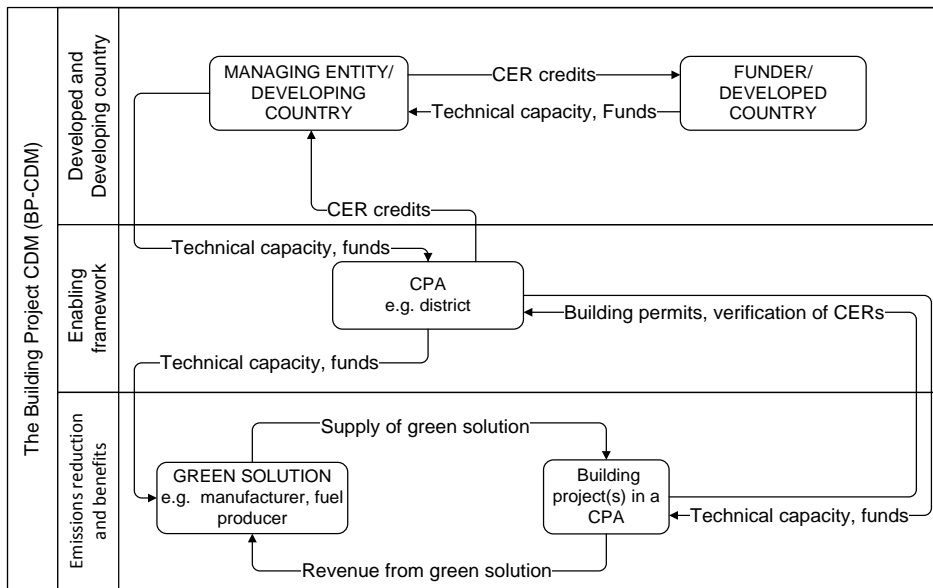


Figure 1: Suggested structure of the CDM related to buildings

In the top level, the developed country offers technical capacity and funds to implement a 'green' solution and in return, receives CERs from the developing country. Technical capacity and funds are extended to the CPAs (see middle level of the diagram) which also extend the same to the implementers of the green solution, who might be manufacturers or building projects. When manufacturers supply 'green' materials to the building project, they receive revenue. If manufacturers have obtained funds from the CPAs in order to manufacture 'green' materials, they can be tasked to offer the materials at lower competitive prices. But, if manufacturers do not claim funds from CPAs, and therefore sell materials at premium prices, the building projects could then redeem the premium from the CPAs. With such incentives, manufacturers can be tasked to be more innovative in search for greener solutions since the demand will be available. For building projects, this could prompt stakeholders to adopt practices that are less carbon intensive. In so doing, the BP-CDM could translate into a market-based mechanism of promoting practices that enhance sustainable construction, whilst advancing the goals of renewable energy policy.

CONCLUSIONS

According to available records, there is currently no registered CDM related to buildings with regard to the construction scope, yet recent studies underscore the potential of building-related CDMs. In response, this work has demonstrated that CDMs can be applied to construction of buildings with a case of housing in Uganda. Through a bottom-up analysis, it was revealed that, within the capital city alone, 20 ktCO₂ of emissions could be avoided annually via a CDM initiative. Since promotion of sustainable development is one of the CDM's objectives, if suggestions in this work are adopted, construction processes in Uganda and other developing countries can contribute to sustainable construction and also support renewable energy policy. However, there were some limitations, such as paucity of data, which are inherent of research in a developing country. For instance, there were no country-specific databases on energy use and emissions. As such, absolute figures presented should not be simplistically interpreted as accurate representation of the cases and the context but rather, a guidance to conceptualise the assertions made. This work focussed on construction of walls only but there would be greater potential if the 'whole building'

was considered. This being an exploratory study, more studies that consider more aspects of the building fabric are necessary to corroborate these findings. In furthering the contribution made by this work, there is need to engage various CDM and built environment stakeholders such as funders (e.g. World Bank), managing entities (e.g. ministries), local authorities, manufacturers, and built environment professionals in order to assess the feasibility of practically implementing the suggested CDM initiative. This is a potential area for further research.

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ASSESSING THE IMPACT OF ENERGY MANAGEMENT INITIATIVES ON ENERGY USE DURING THE CONSTRUCTION PHASE OF AN EDUCATIONAL BUILDING PROJECT IN IRELAND

Jan Gottsche¹ and Mark Kelly

Galway Mayo Institute of Technology, Galway, Ireland

Currently Ireland is aiming to meet the target set by the EU of reducing greenhouse gases (GHGs) by 20 per cent by 2020 as well as targeting a reduction of energy consumption in the public sector of 33 per cent by 2020. Reducing energy use in the construction sector can help Ireland to meet these targets as well as contributing to sustainable development and a reduction of carbon emissions. This research paper outlines the energy reduction initiatives which were implemented on a case study site, which consisted of the construction of four educational buildings in the West of Ireland. The study used an action research (AR) approach to explore the energy reduction opportunities on site. Shortcomings were identified with the contractor's current on-site energy management procedures and quick win low cost/ no cost solutions were then suggested so that only a small investment was required (€1,036). Savings of €28,090.50 were identified on the case study site, across the four buildings, with an equivalent saving of 109.12 tonnes of CO₂ emissions with the overall cost savings representing 25 per cent of the total expenditure on energy usage. The savings of €28,090.50 represents a saving of 0.25 per cent of the project value (€11,243,916). KPIs were also calculated for both phases of the project with the initiatives implemented reducing the KPIs between phases by 79 per cent. Findings suggests that improving site energy use was a key opportunity for the contractor to increase profit margins.

Keywords: carbon reduction, energy management, sustainable construction.

INTRODUCTION

The construction industry is estimated to account for 40 per cent of annual global energy use and 30 per cent of annual GHG emissions (Kospomoulos, 2004; UNEP, 2009). Ireland has a binding EU target of reducing its GHG emissions by 20 per cent relative to 2005 by 2020 and maximising energy efficiency within the construction industry has been identified as a key strategy for the achievement of these EU goals (EC, 2013). Under the terms of the Kyoto agreement in 1997 Ireland agreed to lower its GHG emissions by 13 per cent above the levels which were present in 1990 by 2012 (DECLG, 2000) and subsequently achieved this target (EPA, 2013). Whilst the achievement of this target is a positive outcome in terms of compliance, its occurrence is a direct result of the current economic recession (in 2007 Ireland was 19 Mtonnes of CO_{2eq} away from achieving this target (EPA, 2013)). In Ireland GHG emissions increased by 21 per cent between 1990 and 2000; they were reduced by 3 per cent by 2008 and dropped another 8 per cent in 2009 as a result of the global economic

¹ jan.gottsche@research.gmit.ie

recession. According to the Environmental Protection Agency (EPA) there is a risk that Ireland will not achieve the 2020 target even with ambitious reduction scenarios. The shortfall is projected to be up to 24 Mtonnes of CO_{2eq} for the period 2013 to 2020 with Ireland breaching its annual limits in 2016 (EPA, 2013).

Energy consumption (performance) and CO₂ emissions are often taken into consideration during a building's operating phase. For example in Ireland there are Building Energy Regulations (BER), based on the EU Energy Performance of Buildings Directive (EPBD), and the Building Regulations Technical Guidance Document Part L which set out regulations in relation to energy efficiency during a buildings operational phase. However regulations, and research, dedicated to improving energy usage during the construction phase is lacking. The economic condition of the Irish construction industry will likely take many more years to fully recover from the economic downturn and the inefficient practices and the wastage of energy on site can no longer be accepted. Saving money on energy costs is money that can be added to the profit made on a building project and can also help to increase a contractor's competitiveness. The aim of this paper is to benchmark site energy use, outline the energy reduction initiatives which a construction company in Ireland can use to successfully reduce their energy usage and evaluate how effective these initiatives are on the case study site. To achieve these aims, a number of objectives were set out: (1) Carry out a review of legislation in Ireland and Europe to assess current legislation and policies related to energy usage during construction (secondary research), (2) Test the methods and initiatives set out in a construction phase energy reduction plan by evaluating their implementation and their potential contribution towards reducing energy usage and reducing CO₂ emissions (primary research), and (3) Produce a lessons learned document at the end of the study outlining each initiatives financial assessment and impact on energy usage and CO₂ reduction and record these for future case studies (further research). This is done through a practical application of action research (AR), limited to a single building contractor, working on a selected case study site comprising the construction of four buildings. There are a number of limitations within the study, including; (1) The research will be focusing on on-site energy usage only, the design phase and operational phase will not be assessed; (2) Items such as plant and machinery will not be upgraded or replaced due to the cost involved; (3) The scope of the research will focus on observing behaviour on site and benchmarking quantifiable elements in relation to energy usage.

SUMMARY OF CONSTRUCTION-RELATED ENERGY POLICY AND LEGISLATION

Literature about energy reduction initiatives in other sectors such as the manufacturing industry is extensive (Woroniak and Piotrowska, 2014; Mujtaba *et al.*, 2012; Blackhurst *et al.*, 2011) but the literature in relation to energy usage on construction sites, during the construction phase, is lacking. Various previous studies have focused on improving operational energy efficiency by examining discrepancies between design and actual operational energy performance within buildings (de Wilde, 2014, Firth *et al.*, 2008, Gill *et al.*, 2011, Menezes *et al.*, 2011). However at present the concept of addressing energy usage during construction is not as advanced within the industry (Davies *et al.*, 2015) and construction phase impacts are commonly assumed or ignored by practitioners as their impact is viewed as insignificant (Gustavsson and Joelsson, 2010, Iddon and Firth, 2013). Therefore this study will analyse the construction phase energy use and investigate the impact of reduction measures which can be undertaken during the construction phase of a project. In order to improve

energy efficiency, many construction-related strategies, policies and initiatives have been put in place at both European (Table 1) and national level (Table 2).

Table 1 Summary of the EUs energy policies, strategies and legislation

Year	Title	Author	Summary
2002	Directive 2002/91/EC on the energy performance of buildings (EPBD 2003)	European Parliament	Stated that every building must have an energy performance certificate. Introduced the 'subsidiarity principle.'
2006	Action Plan for Energy Efficiency: Realising the Potential	EC	Aims to reduce consumption by 1.5% each year to 2020. Biggest energy savings could be made in the residential (27%) and commercial buildings sector (30%).
2010	Directive 2010/31/EU on the energy performance of buildings (Recast)	European Parliament	Member states must ensure that by 2021 all new buildings are 'nearly zero energy buildings.'
2010	Energy 2020 - A strategy for competitive, sustainable and secure energy	EC	Construction sector needs to pursue an active energy savings policy and diversify towards non-polluting energy sources.
2011	Roadmap to a Resource Efficient Europe	EC	States that better construction practices and use of buildings in the EU would influence final energy consumption by 42%
2011	Energy Efficiency plan	EC	States that fostering low energy consumption within the construction sector is one of its targets.
2014	Resource efficiency opportunities in the building sector	EC	Proposes a set of clearly defined and measurable indicators, for the assessment of the environmental performance of buildings.

Table 2 Summary of Ireland's energy policies, strategies and legislation

Year	Title	Author	Summary
2000	National Climate Change Strategy Ireland	DoEHLG	Key initiatives; improving energy efficiency in construction, a new house grant encouraging sustainable construction and a review of building regulations.
2006	Implementation of the EPBD in Ireland: Status August 2006	SEI	Notable achievements outlined: the development of a calculation of the energy efficiency of new residential buildings, an update of the Part L Building Regulations to improve energy efficiency and the obligation to carry out a Building Energy Rating (BER) certification for new residential buildings.
2007	National climate change strategy 2007 – 2012	DoEHLG	States that designing for sustainability involves achieving energy efficiency throughout the design, manufacture and construction stages of a building.
2007	Delivering a Sustainable Energy Future for Ireland - The Energy Policy Framework 2007 – 2020	DoCMNR	States that the government will revise existing social housing design guidelines to ensure that all new capially funded housing schemes are sustainable, achieving energy efficiency at the construction stage.
2008	SI No. 229/2008 – EC (Energy Performance of Buildings) (Amendment) Regulations	EC	Mandates the inclusion of BER information in any property sale or rental advertisements.
2008	Low Carbon Homes programme	SEAI	Aimed to support low-energy/ low-carbon buildings as a precursor to revisions in the Irish building regs.
2009	Maximising Ireland's energy efficiency – The National energy efficiency action plan	DoCENR	The plan states that energy efficiency should be considered throughout the entire construction cycle of a building.

2011	Part L Building Regulations – Conservation of Fuel and Energy (Dwellings)	DoECLG	In 2005 Part L permitted an energy load of 150 kWh/m ² / annum for a dwelling. Part L requirements were upgraded in 2007 (40% improvement) and again in 2011 to a 60% improvement for both energy efficiency and CO ₂ requirements. Near zero energy houses are the objective between 2013 and 2016.
2012	Ireland's second national energy efficiency action plan to 2020	DoCENR	Savings of 25% of the 2020 target had been achieved. Attributes the reduced road freight associated with construction industry as being one of the main factors in reducing energy usage within the transport sector.
2012	Delivering our green potential - Government policy on growth and employment in the green economy	Irish government	States that if a business which has not yet addressed its energy usage makes changes which require little outlay then that business can cut their costs by up to 20%, thus providing a boost to their competitiveness.
2012	Roadmap for a National Resource Efficiency Plan for Ireland	EPA, CIT	Aim was to prepare a roadmap which will aid the implementation of a national resource efficiency plan. Subsequently the EPA published this as 'Towards a Resource Efficient Ireland' in 2014.

METHODOLOGY

A case study approach was adopted as this provided a useful vehicle for monitoring activities on site in relation to energy usage. A research partnership was developed between BAM Building Ireland and Galway – Mayo Institute of Technology (GMIT). The works observed during the case study research consisted of two main phases of work. The first phase involved the construction of two new schools on a greenfield site. Doughiska Community College (a 650 pupil post-primary school with a 6,000m² floor area) and Doughiska Primary School (a 450 pupil primary school with a 2,300m² floor area). These works began in January 2013 and were completed in February 2014 with a combined construction value of €10.86 million. The second phase of works involved the construction of two special needs units (SNUs) on site (one for each school). These works began following the completion of the first phase of works and were completed in August 2014. The combined area of the two SNU buildings was 547m² (Primary school SNU has a floor area of 236m² and the Secondary school SNU has a floor area of 311 m²) with a construction value of €1.1 million. The research methodology (Figure 1) comprised of the collection of both primary and secondary research as well as a practical application through AR on a case study site. AR involves the process of intentionally and actively affecting change in a system with knowledge being used to affect the change which then creates knowledge about the process of change (Lewin, 1946).

Critics of action research perceive that action research can be a time consuming process and while this is true, the time spent on the case study site was seen as an integral part of the research project. Without the quantity of time spent on site it would not have been possible to affect change. It could also be argued that the findings of action research are limited in their applicability to the local situation and cannot be generalised across a wider population. This is also true; however as part of further research an additional seven case studies will be undertaken in order to obtain a more representative sample of current practices. The AR involved active participation by the researcher² in the case study contractors company in order to identify, promote and evaluate problems and potential solutions (Fellows and Liu, 2012). The active participation included undertaking site visits, monitoring on site activities and making

² The researcher (author) is a PhD candidate with a background in Construction and holds a BSc (Honours) degree in Construction Management along with an MSc in Environmental Engineering.

recommendations for change to the site management team. The research stage also used qualitative research methods such as observation, field notes and photographs to produce information on the case study site with an aim of assessing the energy usage on site and developing an action plan for reducing same.

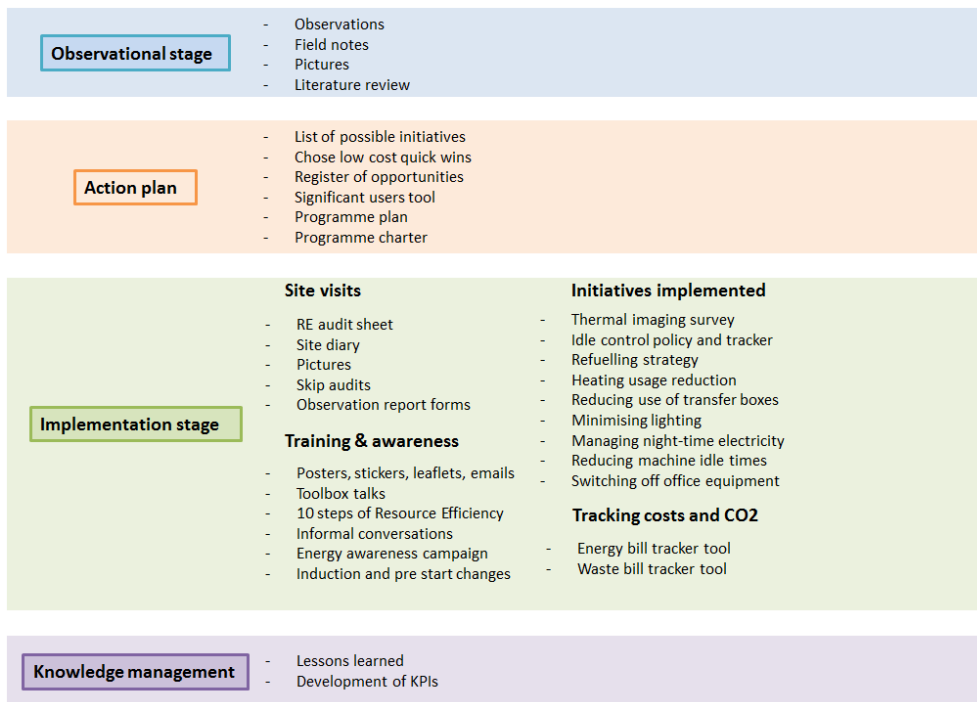


Figure 1. Summary of methodology used on the case study project.

The researcher spent between one and four hours, twice each week on the case study site over a 53 week period. In total there were 82 site visits carried out and during these visits the researcher engaged with the organisation by highlighting areas where energy management could be improved on site. This was done by conducting a resource efficiency audit during each visit. The 'Resource Efficiency Audit Tool,' was developed, by the research team, as a checklist which covered items related to energy usage on site. The tool allows the user to assign a rating of 1 to 5 for each item assessed during the audit and then calculates an average score for the audit. The tracking of these scores then allowed for an analysis of whether or not practices were improving on site between visits. The audit tool helped to identify the specific pattern of energy use; the areas which required immediate attention and indicated what types of energy reduction measures would provide the greatest benefits. After each visit recommendations were made to site management on ways to improve energy efficiency on site through the use of 'Observation Report Forms'. These forms were presented to site management and the issue was discussed and a solution presented. The report forms were also then used by the safety health and environmental (SHE) officer during site management meetings and also formed the basis for site toolbox talks (4 in total) with the employees. In total there were 144 observation report forms presented to site management on resource efficiency measures, with 14 of these recommendations concerning energy usage improvement. Nine of these initiatives were successfully implemented on site following the completion of 75 individual audits of the case study site. The effectiveness of the implemented measures was benchmarked against the baseline performance of the contractor (i.e. the contractors RE performance during the initial observation stage) and cost savings were calculated for each initiative which was successfully implemented. Issues which constantly

showed up during the audit were given additional attention and these issues were developed into additional information for the employees through the use of educational posters and the use of tool box talks. A site diary was also completed during each visit to record what was carried out or achieved during each visit. Once per month the site clerk was also consulted for dockets or bills in relation to energy usage on site, namely, diesel, electricity and gas. The information from these bills was then entered into an *'Energy Bills Tracker Tool'* which is a tool developed by the Sustainable Energy Authority of Ireland (SEAI). This tool allows for the tracking of energy usage on site per month, the total expenditure on energy as well as the associated carbon emissions.

The initial observation period on site took place over the course of four weeks and during this period the researcher evaluated and monitored the methods and actions which were being used on site. It should also be noted that the research phase did not begin at the start of the project as eight months of work on site had been completed when the research phase began. This was unintentional but had the added benefit that the site had been set up using the normal procedures that BAM building use when setting up all of their sites. This meant that any bias associated with setting up the site with the energy efficiency research project in mind was eliminated and that the researcher was able to view the site set up as representative of BAM building. Following the initial observation period on site the first step was to draw up an energy efficiency action plan for use on site which listed all the possible initiatives which could be implemented. Cost analyses were undertaken using the *'Register of Opportunities'* tool available from the SEAI on a wide range of options in order to categorise the options by the amount of capital which would be required to implement them. This tool allows you to calculate possible savings, based on the data you input on the type of equipment you have on site and the possible reduction in running time of this equipment and importantly allows the user to assign a responsibility for each energy reduction task on the list. This list was then distributed to site management so that each person knew their roles and responsibilities in relation to energy reduction on site. A number of items were then chosen from the list, the top priority being low cost/ no cost – quick win type options. On the original energy reduction plan they were then rated as low/ medium or high cost.

The case study work allowed the author to gain a practical knowledge of on-site practices and then carry out an assessment of ways to improve current practice. Training for site operatives was also carried out in the form of toolbox talks (4 new talks developed with each one held twice during the project), posters (7 new posters developed), emails (one email sent to sub-contractors each month, 15 in total) and an information booklet (1 booklet on energy management). Informal conversations also took place with many subcontractors and management on site and these would often occur when an issue was witnessed first-hand and it was possible to make a suggestion immediately in order to improve the work practice in relation to energy management. The research carried out on site was open and transparent at all times with all staff being informed of who the researcher was and that any data gathered was confidential. Permission was granted by the case study contractor to use this case study as a basis for research but any sensitive information such as tender costs are not published in agreement with an ethics and confidentiality agreement with the contractor. The secondary research involved a review of current legislation and policies in Ireland in relation to energy usage reduction within the construction sector as well as an investigation into the response of the industry in relation to the targets set out by the

EU (20 per cent reduction by 2020). The primary purpose of the literature review, as stated by Rhoades (2011) was to assist in understanding the whole body of available information on the topic.

IMPLEMENTATION OF ENERGY REDUCTION MEASURES

Over the course of this single case study site there was €113,397 spent on energy with an equivalent carbon emissions output of 403.8 tonnes³ of CO₂ (calculated by the SEAI tool). These figures can be broken down into electricity (€41,925 with 139.2 tonnes of CO₂), diesel (€58,153 with 207.8 tonnes of CO₂) and gas (€13,319 with 56.8 tonnes of CO₂). Over the course of the site visits and the AR stage of the project there were 9 initiatives implemented on site in order to reduce the energy usage (Table 3). A summary of the energy management initiatives are outlined in the table below along with the cost savings and the reduction in CO₂;

Table 3 Energy reduction initiatives implemented on site

Initiative implemented	Cost savings/ year	Cost to implement	CO ₂ reduction
Reduced the usage of the heaters in the offices by one hour per day (Original usage: 4hrs/ day for 185 wet days).			
- 2 Dimplex blow heaters (2Kw) reduced by 227 hours running time/ year = 908kwh @ €0.14/kwh = €127	€572	€200*	3.03 tonnes
- 7 wall mounted heaters (2kw) reduced by 227 hours running time/ year = 3,178kwh @ €0.14/ kwh = €445			
- *Cost; 5 cabins requiring a thermostat = 5 x €40 = €200			
Turned off the transformer boxes at night time/ weekends and holidays over the course of the project (Original usage: 24hrs per day/ 365 days).			
- 13 transformer boxes (0.4kw when idling) reduced by 7,061 hours running time/ year = 36,716kwh @ €0.14/kwh = €5,140	€5,140	€676*	27.4 tonnes
- *Cost; Auto switch wired to each box = 13 x €52 = €676			
Reducing the amount of festoon lighting bulbs, over lighting in certain areas and running time over the course of the project (Original usage: 10hrs/ day).			
- 183 bulbs (42w) reduced by 1,079 hours running time/ year = 8,293kwh @ €0.14/kwh = €1,161.50	€1,161.50	€0*	6.3 tonnes
- *Cost; Minimal, employees to switch off when not required, better setting up during installation			
Reducing the working time of the crane by two hours each day when possible i.e. busy days on site this was not possible (Original usage: 10hrs/ day plus 1hr warmup period).			
- 300kva generator using 21 litres of diesel/ hour @ €0.79c/litre = €16.59 per hour x 2 = €33.18/ day x 223	€7,399	€0*	27.7 tonnes

³ 403.8 tonnes of CO₂ emissions is the equivalent of the emissions from 85 passenger cars per year, or the emissions from using almost 172,000 litres of petrol or the equivalent of powering 55.5 homes with electricity for an entire year (EPA Greenhouse Gas Equivalencies Calculator).

working days/year=€7,399			
- *Cost; No cost input required – change in working practices			
Reducing the amount of idling time of machinery and saving 5% on diesel costs over the course of the project (Measured with an idle tracker).			
- Total diesel costs = €58,153. 5% saving = €2,907	€2,907	€0*	7.98 tonnes
- *Cost; No cost input required – toolbox talk on idle control			
Turning off site lighting at night (not security lighting) over the course of the project (Original usage 12hrs/ night).			
- 1 st phase (13 months); 272 42w bulbs reduced by 5,432 hours running time = 62,055kwh @ €0.14/kwh = €8,688	€9,247	€120*	28 tonnes
- 2 nd phase (6 months); 35 42w bulbs reduced by 2,716 hours running time = 3,993kwh @ €0.14/kwh = €559			
- *Cost; Installation of auto switch off on main fuse board			
Installing thermostat in the drying room (Original usage per heater: 10hrs/ day for 185 wet days).			
- 2 Dimplex blow heaters (2Kw) reduced by 1,780 hours running time = 7,120kwh @ €0.14/kwh = €977	€977	€40*	5.6 tonnes
- *Cost; Installation of thermostat in drying room			
Turning off (not sleep) computers, laptops, photocopier and plotter each night (Original usage: 24hrs/ day).			
- Desktop drivers (0.4kw) and monitors (0.8kw) reduced by 3,210kwh @ €0.14/kwh = €450/ year	€687	€0*	3.11 tonnes
- Photocopier (0.1kw) and plotter (0.2kw) reduced by 1,694kwh @ €0.14/kwh = €237/ year			
- *Cost; Site clerk to switch off each evening, no additional cost as employee already working in the office			
Totals	€28,090.5	€1,036	109.12 T

All of the initiatives listed in the table above were implemented successfully on site with the exception of the reduction of the usage of the site crane. On busier days, such as days when there were large concrete pours or when pre cast concrete was being installed, this initiative was not possible to implement. However savings were still made in this area on each day except a period of two months during the height of the work activities on site. From a socio-technical perspective the feedback and responses to the initiatives implemented on site were extremely positive and this was investigated in a focus group which was carried out as part of the further research. The cost savings were 25 per cent of the total expenditure on energy usage on site (€113,397) with an equivalent CO₂ emissions reduction of 109.12 tonnes. The saving of €28,090.50 represents a saving of 0.25 per cent of the project value (€11,243,916). The case study contractor is currently working to a profit margin of around 3 per cent so these savings as a percentage of the profit (€337,317) equals 8.33 per cent. If the contractor wants to make an additional €28,090.50 in profit (the value of the savings) then they would have to complete €936,350 worth of work if working to the same profit margin of 3 per cent. As can be seen from the results, it was found that the implementation of energy reduction techniques was achievable and that cost savings could be made in many areas of energy usage with an investment outlay of €1,036.

KEY PERFORMANCE INDICATORS (KPIs)

Following the completion of the first phase of the project it was possible to draw up a number of KPIs from the project. On average the KPIs improved by 79 per cent when

calculated for both phases of the construction project. Table 4 outlines the savings made for a number of the KPIs.

Table 4 KPI improvements between phases of the project

KPI	Stage 1 - KPI	Stage 2 - KPI	Savings made
<i>Cost of electricity per m² of floor area</i>	€4.97/m ²	€1.25/m ²	€3.72/m ² (75% reduction)
<i>Cost of electricity per €100,000 construction value</i>	€395.68 per €100,000 construction value	€83.30 per €100,000 construction value	€312.38 per €100,000 construction value (79% reduction)
<i>Cost of electricity per 100m² of floor area</i>	€497 per 100m ² of floor area	€125 per 100m ² of floor area	€372 per 100m ² of floor area (75% reduction)
<i>CO₂ produced from electricity usage per m² of floor area</i>	13.08kg CO ₂ /m ² of floor area	2.56 kg CO ₂ /m ² of floor area	10.52kg CO ₂ /m ² of floor area (80% reduction)
<i>CO₂ produced from electricity usage per €100,000 construction value</i>	1029.45kg CO ₂ per €100,000 of construction value	170.57kg CO ₂ per €100,000 of construction value	858.88kg CO ₂ per €100,000 of construction value (83% reduction)
<i>CO₂ produced from electricity usage per 100m² of floor area</i>	1292.77kg CO ₂ per 100m ² of floor area	255.94kg CO ₂ per 100m ² of floor area	1036.83kg CO ₂ per 100m ² of floor area (80% reduction)

CONCLUSIONS AND RECOMMENDATIONS

The shortcomings in the energy management on site are clearly evident and have been fully exposed herein. Addressing these shortcomings provided the case study contractor with additional profit (€28,090.50), reduced the projects CO₂ emissions (a reduction of 109.12 tonnes of CO₂ emissions) and also has the added benefit of helping the contractor to become more competitive within the industry (reduced overheads). It is noted that the financial position of the construction industry in Ireland is not what it used to be and thus all the incentives proposed were balanced against any additional costs. The overall cost savings were 25 per cent of the total expenditure on energy usage on site showing that the implementation of energy reduction techniques was achievable and that cost savings could be made in many areas of energy usage. Although the current research produced a number of interesting findings the main limitation for this study was that the observations and initiatives carried out on site were specific to two phases of work on a single case study site. Future research will now take the lessons learned from this project and apply them to an additional seven case study sites across two building companies.

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A SYSTEM FRAMEWORK OF THE COST AND ENERGY RELATIONSHIP OF ZERO CARBON BUILDINGS FROM THE LIFE CYCLE PERSPECTIVE

Jie Wang¹ and Wei Pan

Department of Civil Engineering, The University of Hong Kong, Hong Kong

Zero carbon building (ZCB) has emerged as an innovative approach to addressing the shortage of energy supply and carbon emissions from the building sector. The majority of ZCBs worldwide are mainly driven by government policy, some with financial incentives. In such cases, the social and environmental benefits of ZCBs are prioritised over their economic efficiency. Previous studies of ZCB were largely technical solutions oriented; some examined the impacts of zero carbon design solutions on the building's economic efficiency. However, there is a lack of exploration of the cost and energy relationship of ZCBs. The aim of this paper is thus to develop a system framework of such relationship of ZCBs from the life cycle perspective. The research was carried out through a critical literature review. The life cycle approach was adopted to examine the scopes of costs and energy consumption of ZCBs. A system framework is then developed to indicate how to define the scopes of costs and energy consumption of ZCBs and elaborate how to further proceed to the examination of their relationships. The system framework embraces two layers, i.e. internal and external layers. The internal layer illustrates the interior relationships between the cost, energy and lifespan of ZCBs through a three-dimensional conceptual model; the external layer describes outside context including stakeholder, climatic context and regulatory context. The results of the review suggest that there is a significant extent of inconsistency in defining the scopes of both costs and energy consumption of ZCBs. That is attributed to the confusion and dimness in the definition of both buildings' costs and energy consumption. Such inconsistency hinders the cost-energy relationship from being revealed. The findings should inform the building design decisions about the trade-offs between buildings' economic efficiency and carbon emissions.

Keywords: energy consumption, life cycle cost, zero carbon building.

INTRODUCTION

Buildings take up nearly 45% of the worldwide energy consumption and carbon emissions (Butler, 2008). ZCBs are therefore emerged as an effective approach to alleviating energy demand and carbon emissions from the building sector (Moore, 2012). Despite its prominent environmental benefits, the uptake of ZCBs is presently slow from the global practice. The majority of ZCBs worldwide are mainly driven by government policy, some with financial incentives. In such cases, the social and environmental benefits of ZCBs are prioritised over their economic efficiency.

There is an increasing awareness of the need for adopting life cycle cost (LCC) approach into the trade-offs between buildings' economic efficiency and energy

¹ jwang14@hku.hk

consumption. Buildings are durable and building decisions have long-term consequences (Ryghaug and Sørensen, 2009). Sesana and Salvalai (2013) pointed out as high as 80% of the operational costs of standard new buildings can be saved through integrated energy system designs. Yet often, the mere concern for the investors is the initial capital investment when they make decisions about, e.g. building design, equipment, energy systems (Jakob, 2006; Sesana and Salvalai, 2013). With this praxis, the short-term decision-making fully neglects the ongoing operation energy consumption and associated incurring costs, which may result in a not cost-effective solution.

Important early adoptions of LCC approach have taken place in recent research area of the economic effectiveness and energy performance of ZCBs. However, there is a significant extent of inconsistency in defining the scopes of the cost and energy consumption of ZCBs in the current research, since they are not explicitly formulated in the available guidelines and standards. That is attributed to the confusion and dimness in the definition of both buildings' costs and energy consumption. Such inconsistency hinders the cost-energy relationship from being revealed. Few researches have studied how to explore the cost and energy relationship of ZCBs. Gustavsson *et al*(2010) penetratingly pointed out that connections, trade-offs and synergies between the costs and energy consumption of a building in different phases of the life cycle must be identified, allowing an optimisation of building construction and operation practices to reduce environmental impacts in a cost effective way. Therefore, the purpose of this work is to develop a system framework of such relationship of ZCBs from the life cycle perspective. To achieve this, a literature review was conducted on the existing research. The understanding from this review paves way for the development of the system framework to be proposed.

CRITICAL REVIEW OF COSTS AND ENERGY CONSUMPTION OF ZCBS

A series of terms sharing similar meanings with ZCBs, e.g. zero carbon, nearly zero energy or net-zero energy building are all commonly found in the corresponding literature. These terms initially stem from the building energy policies of a number of different regions or countries, i.e. the United Kingdom, the European Union and United States (DCLG, 2006; Treasury HM, 2011; Crawley *et al*, 2009; EU. Directive, 2010) and are thereafter widely adopted within the research and industry.

Notwithstanding, it is recognized that the grounded assumptions and realizing methodologies for the concepts of 'zero carbon building' and 'zero energy building' (ZEB) are different (Pan and Ning, 2014). The term 'zero carbon building' (ZCB) is sometimes interchangeably congruent with 'zero energy building' (ZEB) or many related terms (Pan, 2014). Hence, the term 'zero carbon building' (ZCB) is used collectively in this paper. Analysis presented in this research builds upon the previous application of life cycle approach on costs and energy performance analysis of ZCBs. An examination of the previous research was carried out to explore the scopes of costs and energy consumption of ZCBs (Figure 1).

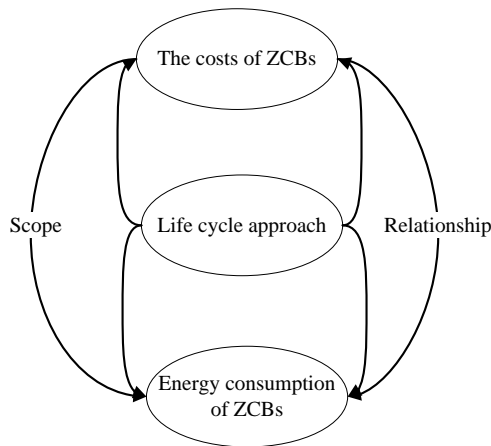


Figure 1: The review framework

The industry to date has recorded a limited number of ZCBs case with verifiable cost and energy performance data (Hootma, 2012). Owing to the insufficient data available to the public of the status quo, there have been scant research on life cycle cost and energy consumption of ZCBs. In some recent research, this research topic starts to be addressed from the lens of case study. After reviewing the existing research, the key technical elements for these studies were thereby identified, i.e. lifecycle stage, building type, cost scope, energy scope and lifespan. The representative researches were selected in order to cover as many different aspects for these five technical elements as possible for comparison and to increase information accessibility. The five technical elements for the enumerated papers were then profiled in the table 1.

Table 1: A review of the life cycle cost and energy consumption of ZCBs

Author	Lifecycle stage	Building type	Cost scope	Energy scope	Lifespan
Zhu <i>et al.</i> (2009)	Installation, operation	residential house	capital investment, cost saving from actual energy consumption (electricity, natural gas, and water)	Operation energy (electricity: actual use)	each technology lifespan
Marszal and Heiselberg (2011)	Installation, operation, maintenance, replacement demolition	residential house	Direct costs for electricity, water and potential penalty	Operation energy (heating, cooling, domestic hot water, ventilation)	each technology lifespan

Table 1(Continued): A review of the life cycle cost and energy consumption of ZCBs

Author	Lifecycle stage	Building type	Cost scope	Energy scope	Lifespan
Kneifel (2010)	Installation, operation, maintenance, end of study period	commercial building	all direct costs for end-user's actual electricity consumption	Operation energy (electricity: actual use)	1,10,25,40 years
Moore (2014)	Installation, operation, maintenance, resale value	residential house	capital investment, costs for electricity and gas consumption	Operation energy(electricity: actual use)	60 years

Lifespan of the building

It is acknowledged that the lifespan applied in LCC research of ZCBs can significantly influence the economic outcomes (Aktas& Bilec, 2012; Mequignon, *et al.* 2013). However, there is no universal standard for what the lifespan of a building should be (Moore and Morrissey, 2014), and yet, longer lifespans are more effective to capture all relevant costs of owning and operating a building (Kneifel, 2010). Different assumed lifespans, like 50 years or 60 years, have been applied within LCC research of ZCBs (Moore& Morrissey, 2014; Morrissey& Horne,2011). Moreover, lifespans are also set based on the study periods (Kneifel, 2010). Last but not least, the functioning times for each individual technology component are occasionally referred to help set the lifespan (Zhu *et al.* 2009; Marszal and Heiselberg, 2011). The variety elucidated above demonstrates an absence of consensus on how to set the lifespan within LCC research of ZCBs.

Lifecycle stage of building

The lifecycle stage division is closely related to the scopes of costs and energy consumption of ZCBs. However, the stages divided in the existing literatures appear to be widely inconsistent, which will consequently affect the consistency of the scopes of costs and energy consumption. As described in table 1, Zhu (2009) only considered the installation and operation stages. While, Aye *et al.* (2000) divided the building lifecycle into three stages, i.e. construction, operation and disposal stages. Furthermore, Cuéllar-Franca and Azapagic (2014) even took the material manufacture stage into the building's lifecycle account, which extends the building's lifecycle upward to the pre-construction phrase. Even though the international standard ISO 15686-5(BS 2012) has already given a proposition in terms of building lifecycle in which the full building lifecycle covers construction, operation, maintenance and end-of-life stages, the lifecycle stages divided in the existing research still vary from case to case.

Cost scope

The cost scope is set to cover the total cost of a building over its lifecycle including upfront capital costs, operation costs, maintenance costs and the building's residual costs at its end of life. The most inconsistency concerning the definition of the cost scope mainly lies to the operation costs. Since LCC covers all the costs arose throughout the building's lifespan, the various expenditures associated with running of

the building, e.g. the costs for energy consumption, water usage and nature gas, etc., certainly should be included. However, not all the energy costs are fully covered in the existing research. Kneifel (2010) solely concerned the costs for the end-user's total electricity consumption. Moore (2014) further covered the costs for both the electricity and gas consumption.

Energy scope

Theoretically, when concerning the energy consumption of a building throughout its lifespan, three phrases, i.e. before-use, use and after-use, will be included into the building's lifecycle, covering the nine key stages of raw materials extraction, transportation to factory, manufacturing, transportation to site, construction and installation, operation, maintenance and refurbishment, deconstruction and recycling or landfill (Pan, 2014). All these phases have to be considered in order to minimize the life cycle primary energy use and carbon emission of a building (Gustavsson *et al.*, 2010). A reflection of the previous life cycle energy research of ZCBs is that most of them have considered only the final energy use in the operation stage. However, few study has focused on the energy consumption implications of before-use and after-use of ZCBs. Typical buildings constructed today use most of the life cycle energy consumption during the operation phase (Winther and Hestnes, 1999; Scheuer, 2003; Adalberth, 2000; Feist, 1997). It seems that operation energy becomes relatively more important to decrease the building's lifecycle energy use, which may result to the sacrifice of the energy consumed in construction or final demolition stages.

Moreover, another reflection is the energy consumption associated with the occupant behaviours. The historical definitions of ZCB or ZEB are mainly based on annual energy use for the building's operation (heating, cooling, ventilation, lighting, etc.) that covers the occupants' entire actual energy consumption (Sesana and Salvalai, 2013; Entrop *et al.*, 2010). Nevertheless, the energy scope is gradually narrowing down with an increasing awareness of the impacts that occupant behaviours have on the energy consumption. Hence, Marszal and Heiselberg (2011) only monitored the energy consumed for heating, cooling, domestic hot water, ventilation in their research.

In conclusion, these reflections drawing on the examination of previous research indicate there is a great extent of inconsistency referring to the scope of costs and energy consumption of ZCBs. Such inconsistency is attributed to two factors: (1) that there is a lack of universal and formal guidelines and standards concerning how to define the scope of costs and energy; and (2) that the scopes of costs and energy consumption are defined with confusion and dimness. Therefore, the inconsistency highlighted here calls for new knowledge of a system framework referring to how to set the scopes of costs and energy. This paper proposes that an understanding of this will facilitate a better grasp of the principles for the life cycle cost and energy consumption analysis of ZCBs and consequently contribute to the further exploration of the cost-energy relationship of ZCBs.

FRAMEWORK OF THE COST AND ENERGY RELATIONSHIPS OF ZCBS

The system framework for the cost and energy relationship of ZCBs is developed in this research that controls the way in which costs and energy consumption are correlated with each other in a holistic manner. The system framework embraces two layers, i.e. internal and external layers. The internal layer illustrates the interior

relationships between the cost, energy and lifespan of ZCBs through a three-dimensional conceptual model; the external layer describes outside context including stakeholder, climatic context and regulatory context, which in turn affect the definition of the scopes of costs and energy consumption. The development of this system framework is based on the reflections that identified through the literature review (Figure 2).

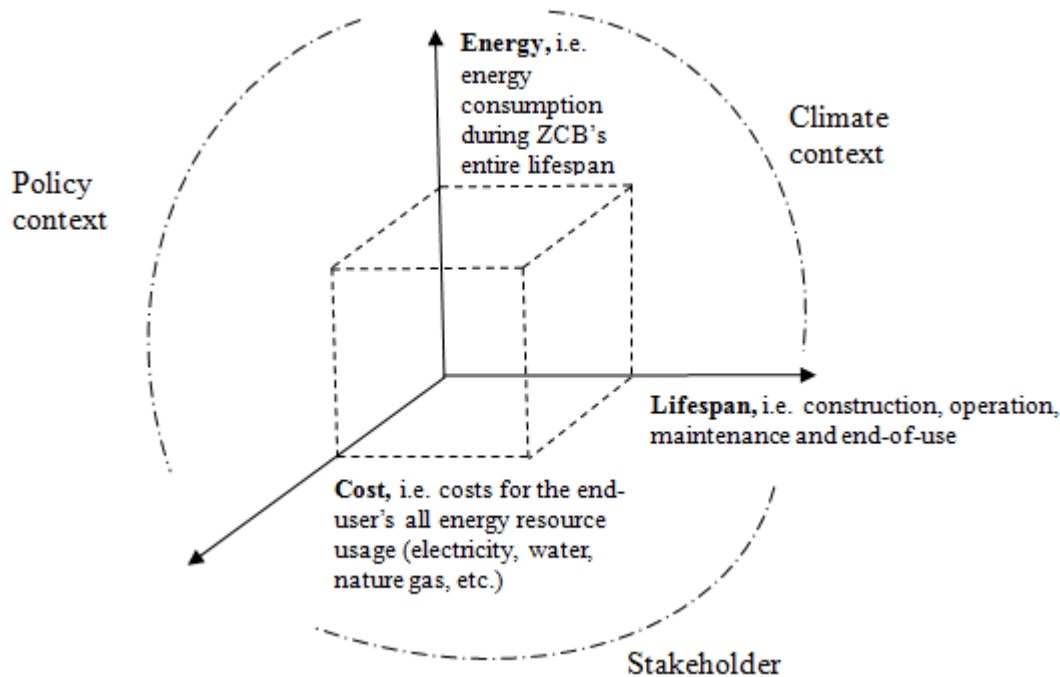


Figure 2: A framework of the cost and energy relationship of ZCBs from the life cycle perspective

Three-dimensional model

The conceptual three-dimensional model describes the cost and energy relationship of ZCBs through its lifespan (Figure 2). The scopes of these three dimensions are closely related with each other. How to define the scopes of these three dimensions are going to be discussed

- Lifespan dimension

The lifespan dimension denotes how to divide the lifecycle stages as well as set the lifespan of ZCBs. The construction and operation stages are prioritized over the maintenance and end-of-life stages for the life cycle costs in the existing research, while the operation stage is prioritized for the life cycle energy consumption. Such preference is primarily attributed to two factors: (1) that there is a lack of strict classification for the lifecycle stages of a building; and (2) the lifecycle phrases are continuously extending backward to the upstream manufactory industry and forward to the recycling business with the growing wider economic and environmental concerns. Drawing on the classification of the ISO 15686-5(BS 2012), this paper considers the full building lifecycle to cover construction, operation, maintenance and end-of-life stages. As for the extra consideration for the pre-construction phrase suggested in the life cycle assessment, the costs for procurement, transportation and other activities involved in the pre-construction phrase are all together included in the construction costs, and also, as for the energy consumption, the embodied energy have already covered all the energy consumed in the pre-use phase. Thus, it is redundant to

specially divide a separate pre-construction stage within the lifespan of ZCBs. Meanwhile, the research lifespan of ZCBs should theoretically be the anticipated service life of the ZCB and any shorter lifespan that is applied cannot ensure sufficient time for the ZCB to maximize its economic efficiency. Yet, extra considerations should be paid to the uncertainties of assumptions on occupant behaviours and the discount rate if longer lifespan is applied.

- Cost dimension

The cost dimension denotes the cumulated costs of the ZCB along its lifespan. The difficulty associated with the costs calculation lies in forecasting the future operation, maintenance and end-of-use costs (Sesana and Salvala, 2013). According to Fabrycky and Blanchard (1991), parametric estimation method should be preferred in predicting the future costs. This method is suggested to be of a lot help to forecast the incurring costs of the ZCB in the operation and maintenance stages. Meanwhile, it has been demonstrated by Korpi and Ala-Risku (2008) that the industry had a clear effect on the cost estimation method used and they further concluded that construction division used a lot of analogy with the estimation. The analogy method can be used solely or in combination with other real estate evaluation approaches, like hedonic pricing method (Morrissey & Horne, 2011), to predict the end-of-use costs of the ZCB, no matter whether the ZCB will be demolished or resold.

- Energy dimension

Major efforts have been made to reduce the energy use for building operation even at the price of increasing energy use in the production phase (Gustavsson *et al.*, 2010). Scholars have been realized that the energy used in the construction and operation stages should be balanced simultaneously. Therefore, there is an increasing awareness for the necessity of taking the embodied energy into the energy balance of ZCBs account. Moreover, in many studies where the energy consumption arose in the end-of-life stages of buildings have been considered, like recycle and landfill (Junnila *et al.*, 2006; Ochoa *et al.*, 2002). However, despite this wide awareness of the energy consumption in construction and end-of-use stages, the difficulty regarding on quantifying the embodied energy and energy consumed in the final stage need to be conquered before achieving energy conservation throughout the whole lifecycle of ZCBs.

Moreover, there is an enormous deviation in terms of occupant behaviours, which are directly relevant to the overall energy use and building economy (Gill *et al.*, 2011; Blight and Coley, 2013; Williamson, 2010). The UK definitions of ZCB transforms from the originally proposed “*genuine*” or “*complete*” zero carbon (which includes both regulated energy for space heating, cooling, ventilation, lighting and hot water; and unregulated energy for cooking, washing, and domestic entertainment appliances (DCLG, 2006)) to regulated energy only (HM Treasury, 2011). Besides that, Moore and Morrissey (2014) also recognized the behaviours of the occupants for energy consuming activities should fall outside the energy scope. Hence, the deviations concerning the occupant behaviours can be excluded by only meeting the regulated energy demand.

The relationships between the cost and energy consumption of ZCBs

Overall, although the dimensions are described separately, they are closely related with each other. The cost and energy consumption of ZCBs will be both determined and affected by some critical factors, i.e. human, materials and building itself. Specifically, as for the human factor, occupant behaviours will significantly impact

the energy consumption of ZCBs and the associated incurring costs. As for the materials factor, the embodied energy will be embedded in the construction materials during the manufacture process and those materials will further consume energy through the construction activities, and also, the purchases of the materials will corresponding increase the construction costs. As for the building factor, the maintenance of ZCBs will cause extra energy consumption and the related costs. Therefore, there are some correlations between the cost and energy of ZCBs and these relationships can be revealed on the condition that the scopes of costs and energy consumption are defined distinctly.

External context

- Stakeholder

Life cycle costing is an economic methodology for selecting the most cost-effective design alternative over a particular time frame. However, different stakeholders have different short-term and long-term interests. The scopes of costs set for different stakeholders are varying from developers to building owners, and ZCBs for different purposes, i.e. residential and commercial buildings, will also have different cost scopes.

- Climatic context

Climatic conditions are another important external context that refers to the climatic zones in which the ZCB is located, such as tropical, sub-tropical, temperate and frigid zones. The climatic context is a significant consideration when simulating the energy consumption of ZCBs. Different countries or regions in different climatic zones have different energy consumption intensities. For example, countries in tropical or sub-tropical zones, like Singapore, may have more cooling energy consumption compared to countries located in mild climatic regions.

- Policy context

The regional or worldwide regulations, standards and policies concerning ZCBs practice closely impact the cost and energy relationship of ZCBs. The definitions and technical requirements for ZCB approach will be clearly illustrated in relevant policies, which give specific requirements for energy consumption or carbon emissions of ZCBs.

CONCLUSIONS

The purpose of this study was to develop a system framework of the cost and energy relationship of ZCBs from the life cycle perspective. Stemming from the critical review, it is concluded that there is a significant extent of inconsistency in defining the scopes of both costs and energy consumption of ZCBs. That is attributed to the confusion and dimness in the definition of both buildings' costs and energy consumption. Such inconsistency hinders the cost-energy relationship from being revealed. Therefore, the developed system framework contributes to demonstrate the correlation between the cost and energy of ZCBs and has useful implications for the building design decisions about the trade-offs between buildings' economic efficiency and energy consumption.

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CLOSING THE ENERGY PERFORMANCE GAP IN ZERO CARBON HOMES – PRO-ACTIVE IDENTIFICATION, PRIORITISATION AND MITIGATION OF CAUSES USING FMEA

Colin Hobart¹, Derek Thomson², Andrew Dainty³, Scott Fernie⁴ and Douglas Drewniak⁵

^{1, 2, 3 and 4}*School of Civil and Building Engineering, Loughborough University, Leicestershire, UK*

⁵*BioRegional, London, UK*

Research suggests that in-use energy consumption of new homes in the UK may routinely exceed design intent. Work to date suggests multiple causes for this so-called “*performance gap*”, ranging from technical/design issues through to procurement and behavioural influences. These varied causes are often difficult to detect and may be viewed as trivial or inevitable by the parties responsible for them. Addressing these issues not only requires concurrent technical and organisational solutions, but also a means of predicting which issues are likely to be significant for a given project. In the manufacturing industry this scenario is often addressed using a methodology called Failure Mode and Effects Analysis (FMEA). Although some building component manufacturers make use of FMEA, there is little documented evidence of this technique being applied at the whole building level. In this paper we argue that FMEA is potentially well suited to addressing the energy performance gap for dwellings, but that the approach must be carefully tailored to achieve this task. The technique is to be tested, by means of an iterative, action research application on a UK development of 400 new-build true zero carbon homes. A critical review of the first iteration describes both the methodological development, and the performance effect produced at project level. This learning in turn informs a discussion of the wider potential for the use of FMEA to close the energy performance gap. It is argued that the method and approach might be applicable to other building types where similar performance concerns exist.

Keywords: energy performance, failure mode effect analysis, FMEA, energy performance, performance gap, zero carbon homes.

INTRODUCTION: THE ENERGY PERFORMANCE GAP

The built environment is widely accepted as being both a major contributor to global carbon emissions, and an arena in which significant improvements are possible (Urges-Vorsatz and Novicova 2008, Oreszczyn and Lowe 2010). A particular area in which emission reductions have been targeted is through improved energy efficiency for new dwellings, and specifically the promotion of an agenda focused on achieving zero carbon homes (Pan and Ning 2015). In the UK incremental reductions in carbon emissions have been sought using design standards applied through the Building Regulations since 2006, and in 2016 a zero carbon standard is due, requiring all new homes to achieve net zero carbon emissions in respect of energy use for heating, hot

¹ c.b.hobart@lboro.ac.uk

water, lighting and ventilation. Whilst this standard is expected to include scope to offset a proportion of emissions using off-site “allowable solutions”, the existing minimum standards for building energy design performance are also expected to be retained and tightened (Zero Carbon Hub 2013; Department for Communities and Local Government 2013).

With demand for new homes in the UK remaining significant despite the recent economic downturn, this policy has considerable potential to assist in managing future carbon emissions. To be effective however design standards must translate effectively to performance in use, and a growing body of research suggests that this may not be the case (Wingfield *et al* 2008, Bell *et al* 2010, Gorse *et al* 2012, Pan and Garmston 2012, Levinson 2015, Pan and Ning 2015). As such, closing this “performance gap” is essential to delivering the carbon management strategy described above, however despite growing academic understanding of its causes, limited progress appears to have been made in improving outcomes in mainstream housebuilding. It would seem that a wholly technical focus on carbon reduction is unlikely to address performance concerns, and efforts must be made to better understand the full range of failure modes that can occur within the socio-technical system that comprises zero carbon building (Pan and Ning 2015). Crucially whilst research data concerning construction related threats to performance has typically been obtained through forensic examination of live build processes and post completion testing, in a commercial context social pressures dictate that improvements be considered alongside their time and cost implications. To achieve mainstream engagement with the performance gap, a set of tools are therefore required which instead allow organisations to predict performance issues in real time on a project by project basis, introduce appropriate mitigation measures, and evaluate their effectiveness in flight.

Performance gap components

The availability of quantitative data to validate design predictions relating to the energy performance of buildings is currently somewhat limited, perhaps due a combination of the relative immaturity of available test methods, limited statutory testing requirements, and commercial and/or reputational sensitivities. Currently utilised as-built test methods include whole house measurement of energy use for unoccupied buildings by means of a co-heating test, elemental testing of the thermal envelope by means of heat flux testing and thermal imaging (Wingfield *et al* 2008, Bell *et al* 2010, Gaze 2010). Airtightness testing is additionally widely used in the UK, however its application to validation of design energy use predictions is somewhat limited, with the relationship between air permeability under depressurisation and its effect on energy use under atmospheric conditions being difficult to calculate and highly context specific (Sherman and Wanyu 2006).

Information regarding the performance gap therefore currently exists largely in case study format, with evaluation typically based upon various combinations of design and modelling evaluation, site observation, pre-completion testing and post occupancy evaluation. These case studies typically demonstrate significant shortfalls in fabric energy performance and the energy efficiency of building systems, both pre and post occupancy. Numerous and multiple causes are proposed for these results, with each project citing a specific suite of problems based upon the organisational context and technical design features (Wingfield *et al* 2008, Bell *et al* 2010, Gaze 2010). Notwithstanding this, some clear cross cutting themes can be identified, and these range across a full spectrum of construction activity, and have implications for a of

stakeholders (Gorse *et al* 2012, Zero Carbon Hub 2014, Pan and Ning 2015). Potential problems begin at initial design and modelling stage, with issues being identified in relation to maintaining the continuity and clarity of design aspiration, and to the appropriate and competent use of modelling to support this. The assumptions adopted at this stage may then face both commercial pressure and lack of technical understanding during detailed design and procurement, resulting in potential for significant unrecognised changes to the design intent. At construction stage, scope exists for further uncontrolled design development and product substitution, as well as ad-hoc development of construction processes, and variations in standards of workmanship, commissioning and installed product performance. Ultimately, occupation brings further potential for misunderstanding or lack of engagement with systems, whilst the relative novelty of the test methodologies themselves means that testing error may also be difficult to quantify.

FMEA

In the manufacturing industry, holistic analysis of systems is commonly conducted using a Failure Mode and Effect Analysis (FMEA). The purpose of FMEA is to identify, prioritise and mitigate potential “*failure modes*” before they reach the end user. A failure mode is a description of the manner in which a failure occurs, and whilst it may be directly linked to a root cause, it may also exist as part of a chain of related failure modes (Mecca and Massera 1999, Hage 2002, Stamatis 2003, McDermott *et al* 2009, Bahrami *et al* 2013). FMEA typically considers failure modes at system, component and part level, and may be conducted at concept, design and/or process stage. The FMEA process consists of three essential elements:

- Identification of potential failure modes, ideally using a whole team approach.
- Prioritisation of failure modes, usually by means of a risk priority number (RPN).
- Mitigation of failure modes by preventing them or controlling their effects.

FMEA is perhaps best viewed as a methodology for enacting these elements, rather than a self-contained tool. It provides a framework to promote rigorous prioritisation and tracking of potential problems, however it is crucial that appropriate additional tools are also employed for identification and mitigation of failures (Mecca and Massera 1999, Stamatis 2003, McDermott *et al* 2009).

FMEA was initially used in military and space exploration contexts and has subsequently become commonplace in other sectors including civil aviation, automotive, nuclear energy and electronics (Liu *et al* 2012). Whilst not widespread, the use of FMEA in buildings has also been previously explored to some extent, and has been documented in applications including ensuring the durability of building components, reducing risk in cladding design and installation, and improving construction safety (Hage 2002, Talon *et al* 2006, Song *et al* 2007). The use of FMEA has additionally been documented in connection with retrospective evaluation of the performance gap, specifically as it relates to building services installations (Tuohy 2013, 2014). Despite the emerging popularity of FMEA as an evaluative method, its use at the whole building level in a predictive role, as would be needed to address the performance gap, is yet to be tested empirically. As noted by Mecca and Massera (1999) this pre-emptive project based application is likely to present considerable technical and organisational challenges, particularly with regards to contractual supply chain arrangements, and the site production environment. In this

paper we report on research that is specifically identifying and addressing these challenges.

METHODOLOGY

The activity described in this paper forms part of a wider research project, which aims to develop tools to assist organisations in effectively implementing the next generation of low carbon housing. The data for the project is drawn from examination of construction processes on a UK development of 400 new zero carbon homes. The development is split into three phases and forms part of a wider plan for construction of 6000 dwellings. Construction of Phase 1 began in 2014 and includes 91 new homes; Phases 2 and 3 are due to start on site in 2015 and 2016 respectively. The research team consists of the housing scheme developer, project manager, architect, main contractor, energy services consultant, and sustainability consultant, working in conjunction with an academic partner. The project therefore includes a substantial element of industry engagement, with team members both providing expertise and data to the research project, and feeding findings back to their respective organisations. The wider aim of the research is to disseminate learning relating to closing the performance gap in the form of a publicly accessible toolkit.

FMEA was included within the research project plan as a means of predicting, prioritising and mitigating design and construction related failures, where these have potential to reduce the energy performance of the completed buildings. Both the effectiveness of FMEA in achieving this aim, and the resulting predictions and mitigation strategies generated were of interest in the context of the overall research project, however only the former is discussed in this paper. During the design stage of Phase 1, the developer, project manager, main contractor, architect, energy services consultant, sustainability consultant and timber frame subcontractor, were asked to suggest “*examples of potential problem areas*” based upon their previous professional experience. These stakeholders were selected on the basis of their having both substantial potential to influence the energy performance of the homes, and a clear commercial commitment to the project at the time at which the process took place. Responses were collected by means of a questionnaire which identified 18 particular categories for these problems, and which also listed 22 examples previously identified by literature review. These categories and examples were provided for guidance of participants, the majority of whom had no previous experience of using FMEA. The “*problem areas*” identified by this exercise were then reviewed by a researcher employed by the sustainability consultant, and used to populate the “*FMEA Schedule*” with a total of 328 corresponding failure modes. To facilitate the next stage of prioritisation, the researcher rated each failure mode in terms of likelihood of Occurrence (O), Severity (S) and likelihood of Detection (D) using standard 1-10 FMEA rating scales sourced from the manufacturing industry. Finally, in accordance with standard practice, these scores were multiplied together to generate the overall RPN's which allow the failure modes to be prioritised for action.

To facilitate mitigation of these failure modes it was decided to raise them at the main contractor's design team meetings. These meetings were the focus of the detailed design and procurement process, and appeared to offer an ideal opportunity to engage with the delivery team to pro-actively consider and address the potential causes of the performance gap. Due to the large number of failure modes identified it was felt to be impractical to attempt to mitigate them all, and indeed a core aim of FMEA is to target resources towards addressing the most significant problems (Stamatis, 2003,

McDermott 2009). The FMEA Schedule was therefore used as a tool to select appropriate items for discussion, and in addition to prioritisation by RPN, further functionality was provided by categorising failure modes according to “*work package*”, “*item/function/process*”, “*responsibility*” and “*time line/project stage*”. This provided potential to group items by a particular task, responsibility or programme stage, according to the agenda and available expertise at each meeting.

Whilst essential for prioritisation, the FMEA Schedule was felt to be inappropriate for presenting failure modes to design team meeting participants; both because participants were expected to be largely unfamiliar with the process and language of FMEA, and also because the sheer quantity of failure modes might be considered overwhelming. The failure modes raised at each meeting were therefore added to a second “*Tracking Schedule*”, which listed selected failure modes and recorded the resulting discussions, actions and ongoing monitoring requirements for each. Failure modes were ultimately presented at 8 design team meetings, however due to time restrictions just 36 failure modes were raised in total, with their selection being further constrained by the availability of specific expertise at particular meetings. Of the 36 items raised, just 13 were deemed to require action, and of these only 5 are recorded as having been substantially resolved as a result of this process.

To capture learning from the above exercise, a review of the FMEA was carried out part way through the Phase 1 construction process. To maximise objectivity whilst retaining access to the experiential learning this evaluation was carried out in discussion with the original researcher, but was designed and directed by a second researcher employed by the academic partner, and who had not been involved in the initial exercise. Evaluation consisted of qualitative discussion of the first researcher's experience of conducting the FMEA, combined with quantitative analysis of the output. Therefore, whilst the methodology described above includes an action research component, this paper presents its findings in the form of an external critical review.

RESULTS

Evaluation of the Phase 1 exercise has produced a number of key observations. These are presented below, as they relate to each core element of FMEA.

Identification of potential failure modes

Review of the FMEA Schedule indicates that significant expertise and experience was mobilised, with a minimum of 18 failure modes contributed by each respondent. Identified failure modes included a wide range of technical, organisational and behaviour related issues, ranging from highly specific failures such as “*Inlet and exhaust operate at different flow rates, resulting in the advertised efficiency of MVHR unit not being achieved in reality*”, to general systemic shortfalls such as “*Thermal bridging through linear junctions*”. 43% of all failure modes were contributed by the timber frame sub-contractor, both providing support for more extensive involvement of sub-contractors, and also highlighting the potential for bias to be created within the schedule; particularly when it is considered that, in contrast, no responses were in this case provided by either the main contractor or the architect. Correct selection and full participation is therefore identified as essential, perhaps in turn suggesting a need for clearer incentivisation to be provided to encourage participation by key stakeholders. A further significant shortfall was identified in the method of elicitation of failure modes, with participants being asked to identify “*problem areas*”, but without the

nature of the problem being fully defined. In this regard it is noted that whilst functional analysis may serve to focus attention on critical areas (Stamatis 2003), this was not applied in this instance. As a result, the questionnaire headings provided as a guide for participants are not closely aligned with the performance gap in all cases, and whilst some such as “*thermal performance of building fabric*” might be expected to channel responses towards relevant function areas, others such as “*design management*” may have been too general to be helpful in this respect.

Prioritisation of failure modes

It is noted that the usual consensus based scoring of failure modes (Stamatis 2003, McDermott 2009) was not employed in the FMEA. Ranking failure modes based upon the opinion of a single individual as took place in this case is considered significantly inferior, as it failed to make full use of the range of expertise available. Additionally, no attempt was made to anchor or calibrate his responses beyond the generic, manufacturing focussed linguistic descriptions provided in the rating scales, and this individual reported a number of fundamental difficulties in respect to the ranking procedure. In particular he felt there was a lack of clarity regarding the metric for assessing “*severity*” with, for example, some failure modes relating purely to energy use, whilst others related fully or partly to occupant health and comfort. This resulted in one particular failure mode being ranked 4th out of 328, despite having no clear potential to influence energy use. The linguistic descriptions provided with the rating scale were of little assistance in this regard, being generated for the automotive industry and therefore expressed in terms of safety, statutory compliance and customer satisfaction. There was also confusion over whether the stated numerical probabilities for “*occurrence*” related to the chance of a failure mode occurring on an individual property, on the current Phase of 91 dwellings, or on the whole development of 400 homes. The probabilities used in the scales were in any case rather low overall, with a rating of 5 for example equating to a 1 in 500 chance of occurrence. Finally a lack of clarity was reported as to whether the probability of “*detection*” related to detection of failure modes prior to the start of construction, prior to occupation, or over the life of the building. This is highly significant, as whilst failures routinely detected and remedied prior to occupation may be undesirable, they would not contribute to the performance gap. Overall, the original researcher reported finding a 1-10 scale unwieldy, and suggested that they would have been more confident using a 5 or 6 point scale. In terms of the results produced, the RPN values produced a relatively weak level of prioritisation across failure modes, with for example, the top rated 20% of failure modes accounting for less than 30% of the total cumulative RPN score. This is perhaps to be expected however, given that the performance gap is widely understood to be comprised of multiple factors.

Mitigation of failure modes

As previously noted, only 36 failure modes (11%) were ultimately presented for mitigation at detailed design stage. Of these only 13 were considered worthy of action by attendees, suggesting a significant disconnect between the team assembled to identify failure modes, and those subsequently tasked with mitigating them. In practical terms it is noted that referencing of failure modes within the “*Tracking Schedule*” was not consistent with the main “*FMEA schedule*”, and that some failure modes were additionally altered when transferred from one to the other.. The result of

this is that although it is possible to see which failure modes have been raised and actioned, it is less clear which have not. Effective filtering of failure modes within the “*FMEA Schedule*” was also found to be problematic, as failure modes were often defined as applying across multiple stages and work packages, and having multiple owners. The result of this was that an unmanageable number of combinations were typically generated; for example whilst only seven individual responsible parties were identified, these were presented in 59 different combinations. It is expected that this issue could be resolved simply by ensuring a primary result is identified in each case.

DISCUSSION

As described above, previous research highlights some significant barriers to addressing the performance gap in mainstream housing. Firstly the performance shortfall appears to be composed of multiple components, which vary between projects depending upon numerous factors including the form of construction, management regime, heating and ventilation strategy and tenure. Secondly, contractual responsibility for resolving the multiple factors referred to above may be distributed across a number of parties. Thirdly, the test methods available to test as-built performance are underdeveloped, with only air permeability testing currently forming a statutory requirement.

It is proposed that an organisational approach based upon FMEA could address the first difficulty directly, allowing relevant factors to be predicted in a structured manner, on a project by project basis. Such an approach also has potential to mitigate the second problem by allowing issues ranging across different build stages and work areas to be managed using a single, relatively simple process. Finally, FMEA is able to operate in the absence of extensive test data, by instead making use of the qualitative expertise and experience of individuals within the project team (Stamatis 2003, McDermott *et al* 2009). However, despite this apparently excellent fit, it has been suggested that FMEA may require substantial adaptation for use in a construction context (Mecca and Massera 1999). In particular there is a need to adjust the scope of the analysis and the metrics by which failure is defined. Where this scope extends to site work there is additionally a need to make allowance for significantly reduced levels of production process and performance related information.

Experience of applying FMEA on the project has underlined the potential usefulness of the method, whilst also suggesting that considerable adaptation and learning may be needed to achieve impact in terms of identifying and mitigating elements of the performance gap. In terms of generating potential failure modes the exercise was successful, producing over 300 issues for consideration. The absence of key stakeholders in this process is however something which should be addressed, and consideration should be given to incentivisation to achieve full team, and ideally group-based, participation. Sub-contractor input was also limited to a single organisation, and a practical means of integrating further trades would also appear to be highly desirable, albeit that this may need to take place later in the procurement process. In terms of organising the identified failure modes a rigorous approach has been identified as being beneficial. Stamatis (2003) suggests that function analysis can be useful in generating high level categories from which to generate failure modes. Categorisation by work package, work stage and responsibility have also been

identified as needing refinement, particularly by listing a single primary result for each in lieu of multiple categories.

Prioritisation of failure modes through the use of rating scales to generate RPNs was more problematic. There appears to have been a fundamental lack of definition of the metric by which the failure modes were to be assessed, the scale of the system being assessed, and the timescales within which fault detection was required. It is considered that these issues could be addressed by providing bespoke rating scales, with descriptions relevant to construction, and to the performance gap in particular. These could additionally be tailored to reflect the expected nature of the failure modes based upon available research; that is failures which are common, non-catastrophic, and not routinely detected. Improved categorisation by function area might additionally be beneficial in this context, by allowing particular areas of concern to be separated into more manageably sized sections. Lastly, it is noted that scoring of scales based on group consensus is recommended (Stamatis 2003), and this should be considered to reduce any bias inherent in a single individual scoring all failure modes, and to increase ownership of RPN values; consideration might also be given to anchoring of rating scales by, for example, agreeing scoring for cases representing high and low values and of which all parties involved have a good understanding.

The final stage of the FMEA - mitigating failure modes - proved to be the most problematic of all. Overall, mitigation was only positively recorded for 5 failure modes, representing just 1.5% of the number initially identified. This success rate does not suggest a good return on the considerable time resource involved in the exercise, particularly when addressing an issue expected to be comprised of numerous factors. Early participation by key stakeholders has been identified as a factor which might go on to improve the understanding and engagement of individuals at mitigation stage. A more time efficient means of presenting failure modes might also be considered, and more effective categorisation of failure modes may assist in this regard by perhaps allowing “*families*” of failure modes to be identified, prioritised and mitigated in relation to particular responsibilities or work packages. Finally, as recommended by Stamatis (2003), monitoring of mitigation of failure modes might be usefully added to the main “*FMEA Schedule*”, to make it clear which failure modes have been addressed and in what way.

Opportunity exists within the research project for iterative development of the FMEA methodology. It is therefore proposed to carry out a design stage FMEA relating to Phase 2 of the site, which consists of a further 69 dwellings. It is intended that this analysis will be adapted wherever possible to incorporate the potential improvements identified above. Following this, a further evaluation will be undertaken to assess the success of these changes, identify further potential refinements, and incorporate these into the research project toolkit for public dissemination.

CONCLUSIONS

Based upon an analysis of the problem, the structured, cross discipline, multi data source analysis facilitated by FMEA appears to have great potential to assist in understanding and addressing the performance gap in construction. Experience of carrying out an FMEA on this research project has however highlighted the considerable challenges associated with utilising the methodology in a new application, and in an environment in which stakeholders have little or no familiarity

with it. In particular the first iteration has identified the following as being potentially beneficial:

- Incentivisation to ensure whole team involvement.
- Group based elicitation and ranking of failure modes.
- Tailored rating scales for prioritisation of failure modes in the context of the performance gap
- The use of function analysis to generate a framework for identification of failure modes relevant to the performance gap
- A more time efficient means of presenting and mitigating failure modes at detailed design and procurement stage
- An FMEA Schedule format covering the full scope of the analysis.

By repeating the action research approach described in this paper iteratively across Phases 2 and 3 of the development, it is expected that significant progress can be made towards developing a commercially viable methodological framework for addressing the performance gap in new housing. Although challenging, the development of such a proactive technique applicable at project level is likely to have wide ranging value, both in terms of improving outcomes, and in reducing project risk.

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HOUSE BUILDING IN SCOTLAND: THE SUSTAINABILITY PERFORMANCE GAP

Gary Tierney¹ and Stuart Tennant²

¹Scotland's Rural College SRUC, Ayrshire, UK

²Civil Engineering and Technology Management, School of Engineering, University of the West of Scotland, Paisley, UK

The construction of very low carbon new homes in Scotland is soon to be mandatory. Despite considerable investment, numerous reports and a deferment, there remain serious question marks over the domestic sector's capability, capacity and motivation to deliver as standard very low carbon homes. The difference between low carbon design and actual building performance has arguably dominated the debate. The 'performance gap' as it has commonly become known, is only one measurement of industry readiness. For successful design and delivery of very low carbon homes, a holistic evaluation of house building in Scotland is required. This is a position paper, exploring the challenge of constructing very low carbon housing. Contrary to the traditional interpretation, the performance gap in the delivery of sustainable domestic construction is arguably threefold; (1) Environmental: the difference between fabric design, thermal performance and resultant energy consumption, (2) social: the gap between supply and consumer demand and (3) economic: the disparity between the economic rewards and the incurred cost of sub-standard delivery. Evidence from previous studies indicates that whilst the notion of very low carbon housing is widely commended and has generated many successful design strategies, the best ways for the industry to deliver the build to the required level remains highly debatable. The low carbon challenge is frequently expressed in 'green', 'sustainable' and 'environmentally friendly' vernacular. Reviewing the literature, this is arguably misleading and a rather gracious evaluation of current industry performance. If, in essence, sustainability ideals are quality ideals then questions need to be asked about construction procedure, process and performance. Addressing the environmental, social and economic performance gap(s) will in all probability require further government intervention, but it may also require a fundamental re-evaluation of sustainable domestic construction and the evolving role of legislators, designers, contractors, consumers and end-users.

Keywords: sustainability, performance, domestic construction.

INTRODUCTION

The construction of very low carbon homes in Scotland is soon to be mandatory (Sullivan, 2013). Despite the imminent requirement to deliver as standard very low carbon homes, there remain serious question marks over the industry's capability, capacity and motivation to realize this level of performance. Key areas of concern include building fabric and energy performance, supply and demand, affordability and client satisfaction to name a few. It has been argued that by taking advantage of synergies between sustainable construction design and parallel initiatives such as smart materials, integrated supply chain management (BIS, 2013) and post occupancy

¹ gary.tierney@sruc.ac.uk

energy performance evaluation, the design and construction of very low carbon homes will be achievable.

Sustainable domestic construction is not a new concept. Over the past two decades, this aspiration has been a significant part of the industry improvement agenda. Early emphasis was placed upon the building fabric, exploring ways to reduce heat loss and energy consumption, the challenge now is much broader with the focus firmly on delivering very low carbon homes from 2016 / 2017. But, despite considerable investment, recent studies suggest (Gorse *et al.*, 2011, Gorse *et al.*, 2012) that there remains a 'sustainability performance gap' between the promise of a zero carbon home and the actual performance of the dwelling as built.

The term 'performance gap' typically refers to the difference between sustainable domestic design (theory) and carbon performance in practice (Zero_Carbon_Hub, 2014). This has stimulated extensive research and development in the technology and science of domestic construction and the need to develop robust models for the design and post-evaluation of the building fabric (Zero_Carbon_Hub, 2014). However, the notion of a sustainability performance gap in domestic construction is not confined to the building fabric and energy consumption.

There is also a 'social' performance gap, this relates to market supply and demand for very low carbon homes. Although the dynamics of the housing market are likely to alter due to direct government intervention, the attractiveness of owning a very low carbon home still has to be promoted as a desirable proposition for new home-buyers. Dependency on the ethical argument, i.e. 'it's the right thing to do' is unlikely to shift consumer perception and create notable demand in the short-term (Fewings, 2009). On the other hand, success also brings tensions. Increasing volume is also likely to put pressure on resources and build quality.

In addition to the 'environmental' (fabric) and 'social' (supply and demand) performance gap there is also an 'economic' performance gap (Craig *et al.*, 2010). The economic performance gap refers to the apparent disconnect between the commercial performance of a house builder and the profit implications (penalty) of delivering less than standard. At present there is little recourse for home buyers dissatisfied with the quality of build and energy performance of their new home and the extended time between taking ownership and a full evaluation makes remedial work even less likely.

Whilst several of the 'performance' problems are scientific and technological in character, others are arguably rooted in the traditional behaviours, culture and structure of an industry largely impervious to substantive change. It is suggested that a mandatory post occupancy evaluation procedure is needed in order to help ensure that low carbon new housing targets are achieved.

This paper is a holistic review of housebuilding in Scotland in the context of the challenges set by performance evaluations. Following a brief overview of sustainable house building objectives in Scotland, the challenges associated with the housing 'performance gap' is reviewed. Three perspectives are presented; (1) an environmental performance gap; (2) a social performance gap and (3) an economic performance gap. The following section outlines the research strategy. The discussion section explores potential corrective measures and suggests that many of the sustainability ideals demanded by government and policy makers are very often quality ideals. The paper concludes with some reflections and identifies avenues for future research.

SUSTAINABLE HOUSE BUILDING IN SCOTLAND

This paper asks a basic question about the holistic sustainability gap between the theory and practice of very low carbon homes in Scotland. Given the imminent legislative requirement to design and deliver zero carbon housing, this is a potentially thorny question for industry stakeholders including government authorities, building design consultants and construction professionals. But, asking this question in the Scottish context in 2015 is pertinent in two related ways that could be applied to other countries. First of all the difference between the high building heating load caused by Scotland's climate and the legacy technical standards that prevailed until fairly recently means that heating energy use, costs and associated carbon emissions in the country are high. Secondly, as a counterbalance to the historical situation, the Scottish legislative aspiration for the very near future is amongst the most demanding in Europe.

The European Commission (EC) has a 20:20:20 vision for the year 2020 in the Energy Performance of Buildings Directive (EPBD) (OJEU, 2010). Key targets for new domestic buildings include a 20% reduction in energy demand, a 20% reduction in carbon emissions compared to 1990 levels by 2020 and a 20% target for renewable energy to be supplied to buildings. To meet the 20:20:20 EPBD commitment, the UK government Standard Assessment Procedure (SAP) (BRE, 2012) is used to evaluate the energy demand of buildings. Adopting this widely accepted algorithm will permit an objective statement of energy performance efficiency over time. Whilst the aspirations of zero carbon housing is driven by the EC, the UK strategy for achieving the 20:20:20 vision is set out in two key documents, the Callcutt Review (2007) in England and Wales and the Sullivan Report (2007) in Scotland.

The Scottish domestic construction industry is guided by the aspirations set out in the government commissioned Sullivan Report (2007) on measures to improve the energy performance of new housing and other buildings in Scotland: 'net zero carbon buildings by 2016/2017, if practical' and, to include eventually the materials supply chain, 'the ambition of total-life zero carbon buildings by 2030'. Of importance, the report makes it clear that the achievement of 'net zero carbon' is to be evaluated using the Scottish building standards requirements for space and water heating, lighting and ventilation, which makes explicit use of the SAP methodology (BRE, 2012). This supports the objectives of the EPBD (OJEU, 2010).

The Sullivan Report (2007) for 2016/2017 recommended a two stage strategy in the design and delivery of sustainable housing in Scotland. The first stage was to amend Scottish energy standards to achieve 'low carbon buildings' in 2010, the second stage was to further revise the Scottish energy standards to achieve 'very low carbon buildings' in 2013. In order to give the domestic building industry adequate notice to prepare for the proposed changes, the Sullivan Report (2007) strongly emphasised the need for information to be disseminated as soon as possible from the date of publication.

In accordance with recommendations set out in the Sullivan report (2007) the Scottish energy standards were changed in 2010 (see Table 1) to deliver a 30% reduction in carbon emissions compared to the 2007 standards. But the second stage (very low carbon buildings) scheduled for 2013 was postponed indefinitely. In response, the Sullivan panel (see Sullivan, 2013) was reconvened for an updated report in May 2013.

The economic downturn that began in 2008 had a negative impact on the construction output in most countries in Europe, including Scotland. The acute economic correction meant that it was necessary to re-think the timetabling for the Scottish energy standards to implement ‘very low carbon buildings’. Despite the delay, government resolve and ambition continues to endorse full implementation of the Sullivan 2007 recommendations and indeed are closely linked to the legally binding carbon emissions reduction targets set out in the Climate Change (Scotland) Act 2009 and the overarching EC EPBD 2010.

New energy standards for housing will be in place in October 2015 (see Table 2). The revised technical standards aim for a 45% reduction in carbon emissions compared to the 2007 standards. Interestingly, Sullivan (2007) had previously targeted a 60% reduction compared to 2007, in carbon emissions by 2013.

Table 1: Current Scottish Building Standard Section 6.0: Energy

Scottish Building Standards Section 6.0 Energy 2010 and unchanged in 2013		
Element or System	U-Value (W/m ² .K)	Air infiltration through the building fabric (m ³ /m ² h at 50 Pa)
Walls	0.19	} 7.00
Floors	0.15	
Roofs	0.13	
Openings	1.50	

Table 2: Proposed Scottish Building Standards Section 6.0: Energy

Scottish Building Standards Section 6.0 Energy proposed for October 2015		
Element or System	U-Value (W/m ² .K)	Air infiltration through the building fabric (m ³ /m ² h at 50 Pa)
Walls	0.17	} 7.00
Floors	0.15	
Roofs	0.11	
Openings	1.40	

Table 1 shows the U-value and air infiltration key performance indicators implemented in the Scottish energy standards in 2010 as recommended by Sullivan (2007) and remained unchanged in 2013, missing the Sullivan (2007) proposed upgrade. Table 2 shows the same energy performance KPIs to be introduced in October 2015. It is worth stating that the 2015 proposed thermal transmittance (U-value) standards are comparable to those required for passivhaus certification.

The Scottish Government ambition for very low carbon housing is commendable. The potential benefits are both local and global. At a local level household energy consumption will be significantly reduced, leading to lower energy costs and improved living standards. At a global level, CO₂ emissions will be reduced and have a positive impact on UK Government carbon emission targets in both the short and longer-term. However, with only a limited amount of time before very low carbon homes become the industry standard for domestic construction in Scotland, many design, build and delivery challenges remain unresolved.

THE SUSTAINABILITY PERFORMANCE GAP

In theory, the design and construction of low and zero carbon housing is both achievable and realistic (Gorse *et al.*, 2011). In practice, the delivery of zero carbon dwellings remains problematic. The success of zero carbon house building is dependent upon three critical aspects of pan-industry sustainable performance; namely, (1) the environmental performance, (2) the social performance and (3) economic performance of the house building sector (see Figure 1).

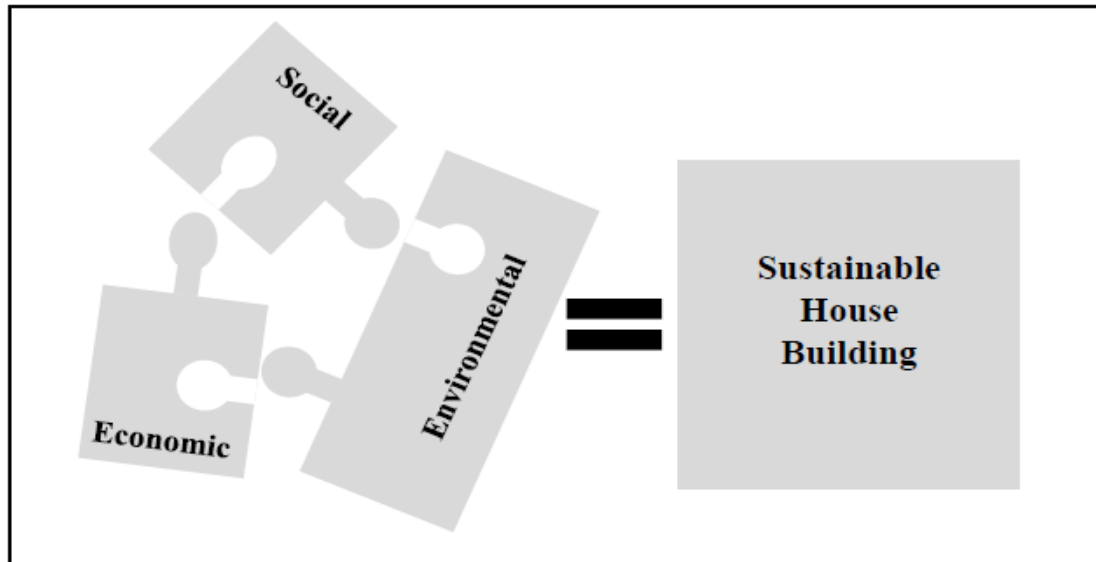


Figure 1: Key components in the delivery of sustainable house building

THE 'ENVIRONMENTAL' PERFORMANCE GAP

Since the publication of carbon targets for housing (Callcut, 2007, Sullivan, 2007) there has been growing interest in the environmental 'performance gap'. The performance gap refers to the difference between the theoretical performance and the actual performance regarding energy efficiency in domestic construction (Zero Carbon Hub, 2014). For many, "the foundation for any zero carbon home must be to ensure that the fabric is delivered to a standard that minimises energy consumption," (BIS, 2010). Whilst the specification and design of energy and carbon efficient housing is arguably 'academic' and founded on widely respected technological and scientific principles, the 'actual' construction process introduces complex variables beyond the scope of laboratory testing. In fact, 'in-situation' testing and performance evaluation of house building and energy efficiency remains extremely rare in the UK.

Reasons for the environmental performance gap are both complex and diverse. Location, design, construction and occupancy behavioural patterns all contribute to the net energy efficiency of the house. In addition to design, recent findings suggest the performance gap is compounded by a range of buildability issues including careless detailing, poor workmanship, lack of applied knowledge and inadequate management / supervisory procedures (Gorse *et al.*, 2012). Given the regularity of sub-standard performance in the domestic construction sector (Craig *et al.*, 2010), it may be argued that sustainable construction ideals are merely high quality ideals. Both (sustainability and quality) contribute to fabric performance that is beneficial to the home owner and government environmental targets.

Exploring reasons for poor quality, as opposed to poor sustainability, highlights the pivotal role of the house builder and the domestic construction industry in general. Many of the underlying causes of poor energy efficiency can be attributed to site practices that are simply sub-standard and unacceptable regardless of the sustainability objectives. Findings from Gorse *et al* (2012) underscore the extent of the problem; 'insulation displaced', 'insulation discontinuity', 'failure to inspect', 'insulation not properly reinstated', 'gaps in party walls', 'incorrect use of tapes and sealants', 'cold bridges', 'incorrect expansion strips', 'junctions not sealed' and 'air leakage around service fittings'. Therefore, to suggest that the performance gap (building fabric) is simply a 'zero carbon challenge' is arguably misleading and also a rather gracious evaluation of current industry build standards.

THE 'ECONOMIC' PERFORMANCE GAP

The economic performance gap refers to the difference between the motivation and capacity of house builders to deliver zero carbon homes and the market value of the industry product. Reviewing recent evidence of fabric performance studies, confidence in house builders and construction contractors in general would appear justifiably limited, but this does not correspond to changes in consumer demand. From an economic perspective, the performance gap is presented as a disconnect between corporate profits and construction standards. As noted in the Review of Housing Supply (Baker, 2004 p.111), "*house builders do not have to deliver a good product, or high levels of customer service, to win market share*".

The growing popularity of off-site construction and innovative design for manufacture and assembly (Dfma) is arguably trying to tackle key issues regarding technical standards and build quality. Promoting the 'industrializing' of the house building process addresses many technological issues but arguably ignores the root cause of poor quality construction. Construction is a people industry. If those with responsibility do not deliver on technical quality, then regardless of its design stage potential, the final product will exhibit failings and defects. As highlighted in previous sustainability studies, damaged panels continue to be installed, construction joints are incorrectly finished and supervisory levels onsite remain inadequate. The pertinent question is why are these practices tolerated? Why are damaged panels installed when it is obvious prior to assembly that they are damaged? Why are assembly joints left open when it is clearly a problem? And why do house builders provide limited supervision on their construction sites when quality standards are widely acknowledged as variable? Admittedly, domestic construction is very difficult to monitor with any degree of confidence. House builders and home buyers arguably accept this. For example, the all too familiar snagging list is simply an expression of sub-standard construction and/or workmanship and/or supervision.

Unfortunately, many of the defects that impair the sustainability values of a low or zero carbon home will be hidden from view and therefore unavailable for detailed inspection from third party regulators and home owners. At present there is very limited post occupancy review of new dwellings, no 'fit for purpose' testing and client feedback to industry bodies appears to be administrative and largely symbolic.

THE 'SOCIAL' PERFORMANCE GAP

Social performance refers to the housing market and the enthusiasm of home buyers to purchase low or zero carbon homes. A number of studies have explored green marketing strategies for sustainable domestic construction (Bevan and Lu, 2013) and

consumer appeal of owning a sustainable, environmentally friendly home (Callaghan, 2014). Frequently, the desire to own a sustainable home is calculated in monetary terms and largely based on an estimate of how much extra money a house buyer is prepared to pay for a zero carbon home. Consequently, the social performance gap is the discrepancy between consumer desire to own a zero carbon home and the financial premium incurred when electing to purchase a sustainable house.

To date, there has traditionally been an upfront financial cost to purchasing and owning a zero carbon home. The upfront build costs are arguably more expensive due to housing developers having to change standard designs, introduce zero carbon technologies (ZCT), hire specialist skills and purchase high specification materials. House builders simply pass any additional expenditure on to the house buyer. The current lack of demand for energy efficient homes (Callaghan, 2014) has arguably compounded the price differential between traditional methods of domestic construction and sustainable techniques and technologies.

The social performance gap is twofold. First, potential home buyers do not regard energy efficiency as a priority when looking to purchase a new home and second, they are not prepared to pay inflated prices, (Callaghan, 2014). House builders have failed to adequately address the problem by continuing to adopt traditional sales strategies. The responsibility for seeking information about energy efficient homes still resides with the consumer (Bevan and Lu, 2013). Given that energy efficiency is not a marketing priority, prospective home buyers are largely left to their own devices regarding salient technical information they require to make an informed judgement. In short, there would appear to be a performance gap between those that produce and those that wish to purchase very low carbon homes.

RESEARCH STRATEGY

This is a position paper. The objective is to explore key challenges facing sustainable domestic construction in Scotland and in particular the performance gap that exists between the theory of very low carbon homes and current industry practice. The spotlight is on house building within Scotland and in particular volume house builders and their construction practices.

The review explicitly excludes contributions from all non-domestic construction, infrastructure (civil engineering), builders' merchants and domestic construction outside Scotland. It is pertinent to note that within the UK, Technical Standards (Scotland) for domestic construction differ from England and Wales. Despite variations, the overarching ambition of both UK and Scottish Parliaments is to deliver very low / zero carbon housing in the short-term. Consequently, many of the issues facing the design and delivery of low carbon homes in Scotland will be representative of challenges experienced in the rest of the UK.

The research method relies primarily on a literature review. The narrative draws on findings and discussion from previous industry studies. Secondary data is provided via anecdotal evidence gathered from recent discussions with a SME house builder and new home-buyers. It is envisaged that further empirical studies will be undertaken to explore the scale of the challenge facing sustainable domestic construction and correction strategies to close the sustainable performance gap.

DISCUSSION

The discussion section explores the readiness of the domestic construction sector in Scotland to deliver very low carbon homes. Addressing the environmental, social and economic sustainability performance gap outlined earlier, three initial strategies are proposed; namely pre and post occupancy certification, quality considerations and improving consumer understanding of low carbon domestic construction. Whilst it is convenient to disaggregate the design, build and delivery of very low carbon domestic construction in to three distinct streams, they are not necessarily mutually exclusive.

PRE AND POST OCCUPANCY CERTIFICATION

Over the past decade, the majority of research interest has concentrated on the environmental performance gap, namely the difference between the theoretical performance and the actual performance regarding energy efficiency in domestic construction. It is therefore fundamental in the delivery of very low carbon homes to fully understand and develop control and correction mechanisms that will permit (1) evaluation of actual performance against the design requirements and (2) raise the knowledge, understanding and profile of very low carbon home ownership.

A key recommendation is the introduction of mandatory post occupation certification for very low carbon homes. This would be an extension of the current building warrant and completion certificate issued by Building Control. Post occupation would allow an independent evaluation of energy performance over an extended period. In Sweden, post occupancy energy efficiency valuation is carried out after two years of new home ownership (Heffernan *et al*, 2012). Results could be collated nationally, energy performance tolerances established and deviation outwith expected energy consumption referred to a 'sustainable housing' industry regulator. The regulator would have license to instigate investigative reports, order remedial work and where appropriate assist with compensation claims for new home-owners. They would also establish a register of repeat offenders.

In the longer-term, the concept of post occupancy certification has a fundamental contribution to make in tackling the environmental performance gap. In the short-term, new home-owners remain vulnerable to energy 'inefficient' housing. As a stop-gap measure and just prior to owner-occupation, building control (or the National House Building Council (NHBC)) could introduce simple non-contact thermometers and thermal imaging to quickly establish thermal performance weak points.

SUSTAINABILITY IDEALS ARE QUALITY IDEALS

Reviewing typical new home-owner defects and snagging lists, it becomes obvious that many of the 'thermal weak points' relate to sub-standard workmanship and inadequate supervision. A significant contributor to poor build quality is the way mass house building in Scotland is structured and subsequently managed. The Scottish construction industry like the rest of the UK is unregulated at the point of entry and in the case of house building very often self-regulating at the point of delivery.

In contrast to many local house builders, very few national house builders directly employ their workforce; as a result house building companies frequently rely on site supervision that is frequently understaffed and over-dependent on the good-will, face-value and honesty of their unregulated / self-regulating subcontractors and suppliers. It remains highly debatable if 'light-touch' regulation can provide the level of product quality and service satisfaction necessary for a very low carbon built environment.

Whilst the list of defects is both familiar and depressing, the perpetrators remain largely unaffected. It may be argued that changing construction industry attitudes regarding quality are greater than the technological and scientific challenges posed by the design and construction of very low carbon housing. Without redressing the balance in favour of the consumer, very little is likely to change. Only at the point where the economic risk associated with poor quality becomes financially punitive will house building companies start to engage seriously with quality build initiatives.

CONSUMER AWARENESS

Much has been made of the construction skills gap in relation to design and delivery of quality sustainable homes (Glass *et al.*, 2008). Whilst not discounting the requirement for greater construction skills training, consumers also require knowledge. Many potential home-buyers are either unaware or currently disinterested in the sustainability credentials of their new home and consequently do not perceive the value of a very low carbon house as a priority. For home-owners it remains the financial cost of a house and potential resale value that dominates the purchasing decision-making process (Fewings, 2009).

The market persuasiveness of “*location is still king*” (Sullivan, 2013 p.17), continues to distort the commercial relationship between cost and quality and energy consumption. A recommendation set out by the Sullivan update (2013) was the requirement to recognize monetary savings attributed to very low carbon construction within property evaluations. Whilst this may reinforce the economic rationality of low carbon home ownership, on its own it is unlikely to alter buyer perceptions.

In addition to house valuations that reflect low carbon construction, consumers also need to better understand the design specifications and technical standards of the house they are buying. This requires home-buyers to become pro-active in seeking information and house builders engaging with potential consumers to disseminate technical information and the performance benefits of very low carbon home-ownership. Without an exchange of technical knowledge, consumer behaviour is unlikely to alter and house builders will continue to exhibit a casual attitude towards quality standards and client satisfaction (Craig *et al.*, 2010).

The supply and demand challenge of the very low carbon home is likely to be exacerbated by recent Scottish Government appeals for ever greater numbers of homes to be built year on year. The surge in the demand for housing units will create tensions within the construction community, stretch regulatory bodies and potentially limit the development and diffusion of technological innovation. In short, significant market demand for new homes may impede industry supply, drive and desire for sustainable house building in Scotland.

CONCLUSION

The Scottish Government ambition to deliver very low carbon housing is both commendable and soon to be mandatory. However, the capacity, capability and motivation of the house building sector to deliver sustainable, energy efficient, high performance homes as standard remains debatable. The challenge is not simply technological, stakeholder expectations of the construction industry need to be raised and a superior quality of service and products demanded and delivered.

There is undoubtedly a requirement for more research and better understanding of the technology and science connected with sustainable domestic construction. The design

and the integration of energy efficient services have a notable part to play but many of the findings cited in recent studies frequently refer to basic failures in construction technology. Defects such as missing insulation, insulation incorrectly placed, gaps not properly sealed, poor workmanship, inadequate supervision, carelessness and misuse of materials are first and foremost exemplars of sub-standard quality. Indeed, many are hopeful that Dfma will help address these issues since sustainability ideals are frequently quality ideals.

Building companies need to take greater responsibility for the delivery and evaluated performance of very low carbon homes. To help achieve this mandatory post occupancy auditing and industry certification should be introduced. Until the sustainability performance gap is addressed in an integrated manner, the construction of sustainable homes in Scotland will probably remain an objective only in theory.

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EXPLORING THE POTENTIAL OF ACCOUNTING FOR EMBODIED CARBON EMISSIONS IN BUILDING PROJECTS IN UGANDA

Nathan Kibwami¹ and Apollo Tutesigensi

Institute for Resilient Infrastructure, School of Civil Engineering, University of Leeds, Leeds, LS2 9JT, UK

With the well-known impacts that the building sector has on the environment, accounting for embodied carbon (EC) emissions in building projects is emerging as an important consideration in project development approval processes. National and international initiatives on accounting for EC have been registered and in some countries, accounting for EC has been made mandatory. However, largely, the potential of accounting for EC is yet to be fully realised due to the prevailing limited integration of EC in building projects. In this paper, the potential of accounting for EC in the building sector in Uganda is explored using a two-stage approach. The first stage comprised of three steps: process discovery – to document prevailing practices; process modelling – to create an as-is system representing prevailing practices, and verification – using semi-structured interviews to ascertain whether the as-is system had been created correctly. The second stage comprised of two steps: analysis and process modelling. Analysis involved drawing evidence from the literature and the verified practices, in order to identify opportunities of introducing EC accounting. Through process modelling, a new (to-be) system incorporating EC was then created. Results from the verification step showed that the prevailing practices had been modelled correctly, further confirming the absence of EC accounting in the referenced context. Analyses revealed that incorporating EC accounting in building projects is plausible but should largely consider national circumstances, such as development approval processes. The overall findings shed more light on the increasingly appreciated phenomenon of accounting for EC in building projects. It is hoped that this work can remind, and at the same time, inform construction management practice and policy of the responsibilities the building sector has towards promoting sustainable construction.

Keywords: embodied carbon, process modelling, sustainable construction, Uganda.

INTRODUCTION

The fifth Intergovernmental Panel on Climate Change report released in 2014 noted that over the past four decades, carbon emissions (greenhouse gases like carbon dioxide) from the building sector have more than doubled (IPCC 2014). Prevailing initiatives suggest that managing carbon emissions requires 'accounting' (BS EN 15978:2011), otherwise, it is impossible to manage what cannot be accounted for. Meanwhile, there is a justified focus on accounting for carbon emissions occurring in the operation phase of buildings (e.g. from heating, lighting, cooking etc.) since this phase accounts for the largest (circa 80%) proportion of buildings' life time emissions (Kua and Wong 2012; Sartori and Hestnes 2007). However, as buildings are

¹ cknk@leeds.ac.uk

progressively designed to stricter operation-energy efficiency, operation carbon (OC) emissions will gradually reduce. Unfortunately, this will be at the expense of increasing the relative proportion and magnitude of embodied carbon (EC) emissions which are associated with various activities (e.g. material manufacture and transportation) of constructing buildings (Iddon and Firth 2013; Monahan and Powell 2011). Therefore, a focus on accounting for EC is necessary.

Accounting for carbon emissions, which basically involves obtaining the mathematical product of process data (e.g. kg of material) and a carbon emission factor (e.g. kgCO₂ per kg), is not a straightforward procedure when it comes to EC. Unsurprisingly, disagreements in this area not unusual especially regarding what EC constitutes (e.g. Sathre *et al.* (2012) and Purnell (2012)). Even standards have not been exhaustive in this regard; the emissions boundary suggested in the European CEN TC 350 standards (BS EN 15978:2011) excludes workforce transportation, yet national initiatives (SFC and Carbon Trust 2010) suggest otherwise. While some commentators have called for development of 'an embodied energy measurement protocol' (Dixit *et al.* 2012), others have concluded that “*there is no single definition of building embodied carbon emissions*” (Li *et al.* 2014: 402). Nonetheless, EC is largely defined, and accounted for, in alignment with boundaries relating to construction projects, namely: cradle-to-gate EC, cradle-to-site EC, cradle-to-construction completion EC, cradle-to-grave EC, and cradle-to-cradle EC (Hammond and Jones 2011; Dixit *et al.* 2010).

Budding practices suggest that EC accounting should be contextualised (e.g. country-based) although their scope limits broader integration of EC in building projects. These practices, whether voluntary (see Franklin and Andrews 2013; RICS 2012) or mandatory (see Brighton and Hove 2013) put emphasis on the cradle-to-gate boundary. While this boundary arguably presents the least complications in accounting for EC, it does not give a complete picture of a building project since activities like construction are excluded. Meanwhile, consideration of other boundaries such as cradle-to-cradle, requires making difficult assumptions (energy-use behaviour, number of renovations, demolition activities, etc.) about the operation phase of a building (Hong *et al.* 2014) and thus uncertainties in EC can manifest. Integrating EC accounting in building projects in a manner that does not underrepresent activities and yet minimises uncertainties requires consideration of the cradle-to-construction completion boundary. However, this boundary necessitates consideration of the whole buildings' development approval process, that is, from planning permission to commissioning. Since development approval regimes vary by country, there is need for significant contextualisation of EC accounting, that is, development of country-based EC accounting systems. In that way, the potential of accounting for EC in building projects will be realised at a broader scale.

In this paper, the potential of accounting for EC in the development approval process in the building sector in Uganda is explored with two motives. Firstly, developing an as-is system describing the prevailing practices and secondly, propose a new system that incorporates accounting for EC. Uganda is the focus because: (1) prevailing efforts of accounting for EC are concentrated in developed countries, with little or no consideration in developing countries yet, embodied energy of buildings in developing countries can be large (Levine *et al.* 2007); (2) due to the authors' acquaintance with construction practices in that context, coupled with other reasons related to ease of data collection; and (3) since accounting for EC can directly or indirectly offer benefits such as driving innovation, use of locally available materials, and creation of

employment opportunities (Embodied Carbon Industry Task Force 2014), there is a business case in arguing for EC accounting in such a developing country.

METHODOLOGY

In order to explore the potential of accounting for EC emissions in building projects in Uganda, the prevailing practices were described and new proposals suggested.

Describing the prevailing practices

In order to describe the prevailing practices, process modelling was used to create a process model of the development approval process (as-is system). A system can be defined as an “*integrated composite of people, products, and processes that provide a capability to satisfy a stated need or objective*” (Sage and Rouse 2009: 1363).

Usually, process modelling initiatives are motivated by the desire to improve a system and such initiatives should begin with describing the as-is state of affairs (Debevoise and Geneva 2011). In order to develop the as-is system, three steps were followed: process discovery, modelling, and verification.

Process discovery was intended to discover process space, process topology, and process attributes (Debevoise and Geneva 2011; Verner 2004) of the existing development approval process. Under process space, the intention was to describe all the relevant sub-processes and their associated interaction. This was based on review of relevant literature such as regulations, together with the authors’ experience and anecdotal evidence about the context. In process topology, the aim was to identify activities and their flow logic. The output from process discovery was a summary of sub-processes, with their corresponding activities, and flow logic.

Modelling was conducted to produce a process model diagram of the as-is system and this involved defining process scope, delineating high-level process map, and drawing the process model diagram. In defining process scope, the important aspects addressed included: how a process starts, what determines when it is complete, and the different ways in which it could end (Silver 2011: 57). Meanwhile, the high-level process map involved enumerating the major activities of the process. The high-level activities also acted as the process-phases of the overall process model (Debevoise and Geneva 2011). Using Microsoft Visio 2013 software, a process model diagram with two tiers was constructed. Essentially, activities identified in the high-level formed the first tier of the diagram which was expandable into the second tier consisting of child-level diagrams. Inbuilt software functions were used to check the integrity of the process model with regard to the process modelling rules. The adopted modelling rules conformed to the Business Process Modelling and Notation (BPMN) modelling grammar (OMG 2014). This notation, which is widely preferred in process modelling (Silver 2011; Takemura 2008), provides graphical constructs and rules prescribing how to combine the graphical constructs in order to describe processes (Recker and Rosemann 2010; Wand and Weber 2002).

Verification was conducted to empirically ascertain whether the as-is system had been constructed rightly. A case study was appropriate since it can be used to describe events, processes, and relationships (Denscombe 2010); an embedded single-case study design (Yin 2014) was adopted. Two local planning authorities that have high rates of construction activities were purposely selected: 'Kampala' district and a neighbouring 'Kira' town council. Eight informants, considered as the subject matter experts (SMEs), four from each authority (i.e. physical planner, architect, engineer, and environmental officer) were purposely selected. Semi-structured interviews

involving face-to-face interaction and use of charts were used to collect data since they accorded flexibility to a discussion and availed respondents a chance to expound ideas (Creswell 2014; Denscombe 2010). In the interview procedure, the as-is system was presented to the informants in form of a chart to offer them an opportunity to easily visualise the end-to-end view of the described processes unlike verbal or written prose. Informants were then asked to describe how the processes shown in the chart are executed in practice. The discussions were recorded and later transcribed.

Using Nvivo 10 software (Bazeley and Jackson 2013), a directed content analysis approach (Hsieh and Shannon 2005) which falls under qualitative data analysis techniques was followed in analysing the data. Directed content analysis is usually used to “*validate or extend conceptually a theoretical framework or theory*” (Hsieh and Shannon 2005: 1281). In the approach, codes/themes were predefined based on the as-is system. For instance, an activity in the as-is system described as 'prepare documentation' was converted to a theme of the same name. Supportive words and phrases in the data were then coded to such a predefined theme and where predetermined themes were deemed inapplicable, new ones were defined. This approach was not largely amenable to statistical data processing, since the output was mostly nonnumeric, and as such, evidence was presented by showing coding references (i.e. number of times an aspect is coded), codes with exemplars, and descriptive excerpts from interview transcripts (Hsieh and Shannon 2005). The analysis structure was grounded in theoretical propositions that led to the investigation, together with examination of rivalling explanations (Yin 2014). The proposition stated that the as-is process model developed was not a true representation of reality; confirming this proposition required examining rivalling explanations such as evidence showing that the system did not represent reality. The proposition was to be rejected if no sufficient rivalling explanations were found. Meanwhile, this research involved human participants and therefore ethical requirements such as seeking for ethical approvals were appropriately fulfilled.

Derivation of proposals

Critical reflection using literature and the ascertained prevailing situation, as depicted by the as-is system, was carried out in order to identify opportunities to incorporate EC accounting. Consequently, a new (to-be) system was proposed and presented as a process model diagram.

RESULTS AND DISCUSSIONS

The structure of the as-is system, results from its verification, and the structure of the new (to-be) are all presented and discussed.

As-is system depicting the prevailing practices

The as-is system (see Figure 1) consists of three linked pools, each representing a sub process. Each pool has activities (rounded-edge boxes) connected with arrows and diamond-shaped decision gateways to show logic of flow. Activities are presented at a collapsed high-level but contain child-level activities when expanded. The major sub-processes contained in the development approval process in Uganda were: (1) environmental impact assessment (EIA) sub-process (National Environmental Act Cap 153, Environmental Impact Assessment (EIA) Regulations 1998); (2) building project (BP) sub-process (Physical Planning Act 2010, Building Control Act 2013), and (3) development permission (DP) sub-process (Physical Planning Act 2010, Building Control Act 2013). The EIA sub process (refer to EIA pool in Figure 1)

started when there was a need to carry out an EIA, born by the fact that the building project fell into a category for which EIA was mandatory. The EIA sub process started with an activity of 'prepare brief' and was complete when the developer was informed by the authority about the decision of approval, rejection, or deferring of the project. The BP sub-process (refer to BP pool in Figure 1) was envisaged to start when the client or developer solicited services of a consultant to work on a prospective building. It started with 'prepare inception report' and ended with commissioning of the completed building. The need for permission to undertake a development triggered the DP sub process (refer to DP pool in Figure 1). It started with 'prepare documentation' and was complete when the applicant/developer was informed of the decision. The decision was observed to be in various states: approved conditionally, approved unconditionally, rejected, or deferred.

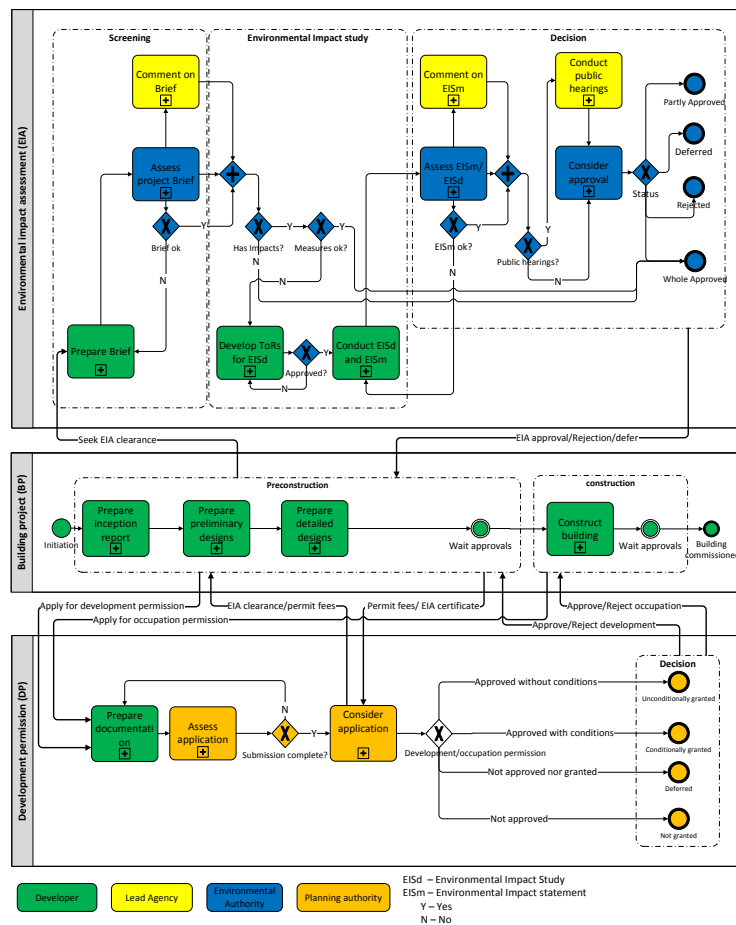


Figure 1: Existing development approval process in Uganda (as-is system)

Verification of the as-is system

At the end of a two-week data-collection period, interviews each lasting about 30 minutes had successfully been conducted with: two physical planners, one engineer, one environmental officer, one health inspector, one environmentalist, and one land surveyor. Unsuccessful appointments warranted inclusion of some other SMEs who were not on the initial list. Analyses revealed that generally, all the three sub-processes had sufficiently been modelled correctly. An example of coding references and exemplars with regard to one activity/theme selected in each of the three sub-processes is shown in Table 2. Most high-level activities/themes registered coding references and exemplars. Upon inspection, no significant rival explanations were identified in the three sub process. As such, it was concluded that the as-is system was

reliably a true representation of reality. For the EIA sub-process however, the activity of conducting public hearings did not register any coding references but no rival explanations were found. This perhaps implied that public hearings were a rare occurrence according to the informants' experiences or usually avoided because of their associated consequences. Six of the linkages (refer to Figure 1) of the process model (i.e. apply for development permission, approve/reject development, seek EIA clearance, EIA approval/rejection/defer, apply for occupation permission, and approve/reject occupation) connecting the three sub-processes were also verified to be reliably accurate, since they registered coding references and exemplars. For instance: “clients bring in files through customer care, that is, we have a tent outside there” (Physical planner A) – implying application for development permission; “...we then approve the drawings and we give a client a copy, we also issue an approval letter (Physical planner B) – implying approval of development; and “...you’ve finished the structure, you [developer] have to apply for an occupation permit (Physical planner A) – implying applying for occupation permit.

Table 1: Coding references and exemplars

	High-level activity		Exemplars
	Theme description	Coding ref.	
DP	Assess application (by local authority)	7	<p>“...when you submit the drawings, we make for you an assessment [...] we have acknowledged that we have received the drawings” (Physical Planner B).</p> <p>“The physical planner looks through to see those that meet the basic requirements for assessment” (Physical planner A).</p> <p>“My role there is to see a adequacy of the plot, the proposed development. I check plot dimension, plot area and shape” (Land surveyor).</p>
BP	Construction (by developer/consultant)	6	<p>“We don’t have too much capacity to be everywhere at the right time, meaning, some construction can go on without being detected, yet they are building wrongly” (Health Inspector).</p> <p>“Then after approval, we have what we call a Job card, its yellow. It shows all the stages of construction of the building. So the building inspector is supposed to tick [...] you call him, he signs [...] so per stage you have to call him” (Physical planner A).</p> <p>“...we are supposed to assess after the project is complete, more especially perhaps may be when we demand for an occupation permit (Physical planner B).</p> <p>“If it is a storied building/ high-rise, vertical developments, there are other requirements that are needed, maybe supervision...” (Physical planner B).</p>
EIA	Prepare Brief (by developer/consultant)	2	<p>“So, the way it all starts, you have to have a project brief” (Environmentalist).</p>

Inspection of some variations which were identified between the process model and empirical observations revealed that in the process model, some activities had been captured at an aggregate level. This confirmed that regulations do not necessarily have to be prescriptive (Penny et al. 2001), implying that there can be flexibility for the practice to prescribe how to comply. Indeed, in the EIA sub-process, empirical evidence suggested that the practice is structured into three phases: screening, EI study, and decision-making. The revised model took account of these finer details (refer to EIA process pool in Figure 1). Similarly, some observations were also noted on the linkages connecting some sub-processes. Between the BP and DP processes, it was discovered that usually, the EIA process is initiated in the DP process but not in the BP process as earlier envisaged. An environmental officer held that “once I request for an EIA, the client goes and gets a consultant who must be registered with

NEMA [National Environment Management Authority]”. This implied that the developer was advised on whether an EIA is required only after making an application for building permit. Another identified linkage was one related to payments of permit fees. When the application was assessed, the developer was notified about the amount of fees; “*the clients come back, we call the clients, and they pick those plans, then they go and pay*” (Physical planner A). This extra information warranted addition of two new linkages (i.e. EIA clearance/permit fees, and Permit fees/EIA certificate) that had not been initially captured (see Figure 1).

Proposal for introducing embodied carbon accounting

Besides verifying that existing practices had been modelled correctly, it was empirically ascertained that EC accounting in building projects was not carried out. This was not surprising since, EC accounting is relatively a new area and perhaps, less would be expected of such a developing country like Uganda. Therefore, this warranted for a need to introduce a ‘new’ sub-process of accounting for EC emissions. This new sub-process was appropriately integrated in the existing sub-processes of EIA, DP, and BP as shown in Figure 2. However, as argued in this work, the EC accounting boundary should be cradle-to-construction completion. This implies that the EC considered should include manufacture and transportation of materials, transportation of labour/workforce, use and transportation of plant/equipment (Kibwami and Tutesigensi 2014). To take into account of these suggestions, various activities within the EIA, BP, and DP sub-processes would have to be revised. As part of EIA, EC accounting could be included as a requirement for environmental approvals. Similarly, as part of DP, EC accounting of prospective projects could be included as a requirement for issuing building and occupation permits. With regard to BP, preliminary carbon estimates can be made during early designs, detailed carbon estimates during detailed designs, and interim carbon estimates during the construction stage. Similar to practices documented elsewhere (see Moncaster and Symons 2013), there would be a need to identify (or develop) appropriate EC calculation methods and software tools based on databases that take into account national circumstances. Certainly, empirical evaluation of any proposed system is necessary to ascertain whether the system fulfils acceptable principles of carbon accounting such as relevance and transparency (WRI/WBCSD 2005), whether it can improve sustainability as expected of a carbon measurement initiative (RICS 2012), and whether there are any challenges of implementing it in practice.

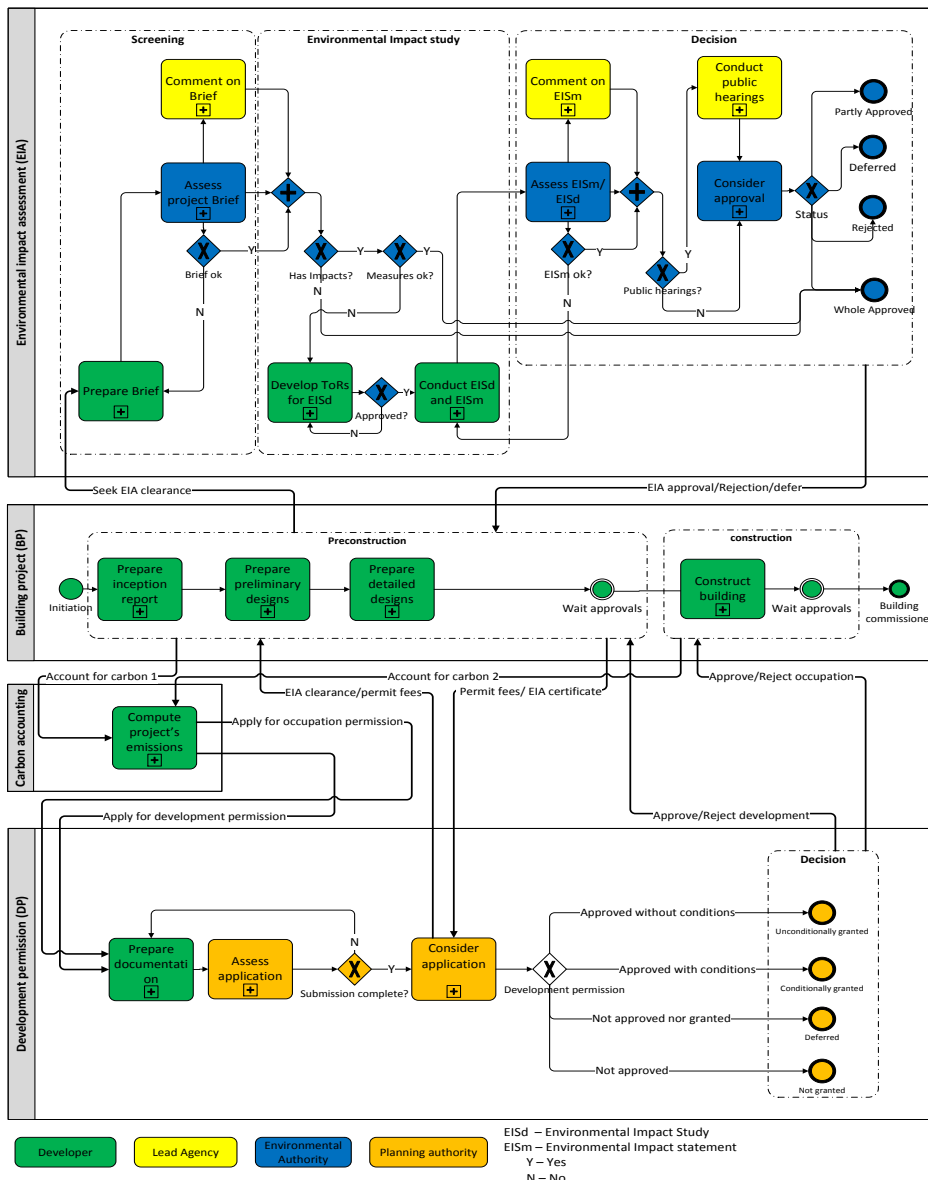


Figure 2: Proposed development approval process for Uganda (to-be system)

CONCLUSIONS

With the recognised need for reducing carbon emissions associated with buildings, the importance of accounting for EC emissions cannot be over emphasised. However, there is limited integration of EC accounting in building projects due to the cradle-to-gate boundary used in prevailing accounting initiatives. This, it has been argued, limits greater realisation of the potential in accounting for EC. The suggested remedy requires considering the cradle-to-construction completion boundary, which demands significant contextualisation of EC accounting. Using a context of Uganda, the potential of accounting for EC in building projects was explored. An as-is system which describes the prevailing development approval process was derived using process modelling. From a case study involving two local authorities, it was empirically ascertained that accounting for EC was not carried out. Consequently, in form of a process model, a system that integrates EC into the development approval process was proposed based on the cradle-to- construction completion boundary. It is hoped that the proposed system will lead to greater realisation of the potential of incorporating EC in building projects in order to promote sustainable construction.

However, for the proposals to be implemented, further research is necessary to develop suitable calculation methods, software tools, and databases for quantifying carbon emissions. In addition, empirical research is necessary to evaluate any such proposed system. Such evaluation would involve, among other issues, ascertaining whether the system fulfils acceptable principles of carbon accounting, whether it can promote sustainable construction, and identifying the challenges of implementing it in practice. Meanwhile, the methodology that was employed in this work has demonstrated the utility in using process modelling supported by verification interviews. The authors recommend this methodology to other areas of construction management research especially where research questions related to ‘improvement of a prevailing situation’ are involved.

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ADDRESSING THE THERMAL PERFORMANCE GAP: POSSIBLE PERFORMANCE CONTROL TOOLS FOR THE CONSTRUCTION MANAGER

Christopher Gorse¹, David Glew, Dominic Miles-Shenton and David Farmer

School of the Built Environment, Leeds Beckett University, Leeds, West Yorkshire, UK

Construction practice has failed to deliver buildings that consistently meet their expected thermal performance; however, examples of good practice do exist. Buildings can be designed and built within acceptable tolerances and meet nearly zero carbon standards. Unfortunately, due to the negative implications associated with the performance gap there have been attempts to divert attention from measurement, with some being critical of methods that were used to identify the variance in building performance. However, the tools have proven reliable and the practice of thermal measurement which was once limited to scientists is finding its place in industry. Measurement is becoming more accepted and different tools are being used to assess thermal performance. The tools can add value to inspections, building surveys and assist with quality control. Construction professionals, not least construction managers, are gaining valuable insights through research undertaken and observations gained. The tests reviewed provide new methods of capturing evidence on building performance, thus allowing valuable information on the quality of design, workmanship and process to be gained. Use of thermal measurement and analysis tools should result in further improvements to building performance. The data from major performance evaluation projects are reviewed and presented.

Keywords: building performance, quality assurance, zero-carbon buildings.

INTRODUCTION

Approximately 34% of man-made emissions come from the built environment representing 45% of the UK's total carbon footprint, with space heating loads accounting for the greatest proportion of emissions (Palmer and Cooper, 2013). Heating loads make up 62% of the total energy used in homes (DECC, 2013; 2014). Thus, the construction industry carries a significant burden, being responsible for the largest share of emissions by some way. Thus, there is pressure to improve the thermal performance of buildings and make substantial reductions in the energy required to heat and condition them.

The European Energy Performance of Buildings Directive (2010) and the demand for a nearly zero standard for dwellings by 2018, represents a significant challenge to the construction industry. The UK's aspirations to achieve nearly zero energy buildings during a tighter timeframe (by 2016) is ambitious, especially since there are relatively few studies that have measured thermal performance and understand how buildings behave when heated. Due to the lack of measurement, most professionals do not know when energy efficiency targets have been achieved. To achieve the reduction in

¹ c.gorse@leedsbeckett.ac.uk

carbon emissions required, improvements in thermal performance must be real, achieved in practice and not limited to aspirational designs. Unfortunately, differences between the designed thermal performance and that actually achieved have been found. Regardless of the aspirational design standard, research has revealed a considerable discrepancy; some buildings tested in the field can be double that expected (Stafford *et al.*, 2012a; 2012b), it is not uncommon for dwellings to experience 60% greater heat loss than designed (Gorse *et al.*, 2013; 2014).

The findings do not provide an example of an industry that is in control of performance. The range of performance across the dwellings is dispersed and requires process improvements to ensure buildings are delivered within acceptable levels of thermal performance. Before construction managers can achieve the degree of process control needed, they need the tools to measure and monitor the performance of the buildings being assembled. Where discrepancy from designed performance is large, remedial action will be necessary to bring performance back on track. However, as there is little agreed practice with regard thermal measurement and performance, acceptable levels of tolerance have not been established. Work is required to understand the discrepancy that is acceptable for construction practice so that a workable tolerance can be set.

UK specific targets will not be achieved unless tolerances are understood and buildings are designed with a suitable safety margin. The errors in design and construction should be removed by measurement and use of systems that eliminate assembly problems. Processes to prevent substandard materials being used and unauthorised product switching, should also be addressed. There are tools being developed which can help alleviate such practice. An examples of real time process tool being applied to capture design, survey and performance data include the VRM technology system being tested through the BRE S-Impler Innovate UK project (BRE, 2015). The process issues can be overcome if the processes that lead to the desired performance can be recognised. Unfortunately there is limited use of the tools that actually measure and establish how the building performs.

Method

An overview of the methods used for assessing thermal performance, their reliability and possible applications are discussed. The observations are taken from the findings of a number of research projects undertaken at Leeds Beckett University. To provide examples of the findings, the discussion uses some primary data to demonstrate the performance of the tools. Further detail on the research methods can be found within the following research reports:

16. Joseph Rowntree Housing Trust Temple Avenue Projects (CeBE, 2012)
17. Coheating methodology (Johnston *et al.*, 2013)
18. Technical Reports (CeBE, 2014)
19. Stamford Brook reports (CeBE 2014; Gorse *et al.*, 2014)
20. DECC Core Cities reports (Gorse *et al.*, 2014)
21. Saint Gobain Energy House (Farmer *et al.*, 2014)

Measuring thermal building performance: Reliability, validity

The methods used for measuring a building's thermal performance have become a topic of debate. The coheating test (Johnston *et al.*, 2013) has been influential in recognising that many dwellings were not achieving their expected performance (Stafford *et al.*, 2012; Gorse *et al.*, 2014). However, following Butler and Dingle's

(2013) investigation of whole building test methods, some doubts were raised over the reliability of the test. However, the research brought into focus what can go wrong where research methods are not applied correctly. The heat loss measurements at the heart of this debate are often difficult to capture, and with so many influencing variables, which need to be accounted for within the analysis, the current methods are largely limited to academic study. The field tests are exposed to naturally occurring phenomena, variable test conditions are expected and the reliability of results must be considered against the environmental changes that take place. Amongst other observable conditions, analysis of heat loss needs to take account of irradiation, humidity, moisture, temperature, wind etc. In some instances, the external test conditions may be so variable that tests are not applicable nor the results reliable. When external conditions cause significant changes to the internal conditions, such that they affect the ability to measure fabric performance all is not lost. Such results are often indicative of fabric failure. For tests to be undertaken on the building fabric, the fabric must offer a level of resistance and provide some effective envelope seal. Where thermal bypasses of the fabric and air changes are high, the thermal resistance offered by the fabric can be so poor that energy assessments monitor the changes in the weather rather than the building fabric resistance. Initial results of the DECC research found some properties experienced air change rates exceeding 20 changes per hour, meaning that any heat in the building was flushed out with changes in the wind every few minutes (Gorse, 2014). In the same study some buildings were found to be so leaky that the test could not obtain reliable results. Where the envelope does not offer an effective fabric enclosure the fabric cannot be tested. As with all methods there are limitations, those affecting coheating are identified in the method (Johnston *et al.*, 2013).

Tests have been conducted to explore the reliability and validity of the coheating test. In January 2010 a research team undertook a coheating test on a 2 ½ storey detached dwelling using the Whole House Heat Loss Test Method (Wingfield *et al.*, 2010). The test was undertaken as part of a project designed to test the thermal performance of prototype dwellings in situ for the Derwenthorpe housing development. The Heat Loss Coefficient (HLC) resulting from the January 2010 coheating test was 132.9 (\pm 1.5) W/K. In December 2012 a different research team undertook a coheating test on the same dwelling in accordance with the 2012 iteration of the Coheating Test Method (Johnston *et al.*, 2012). The HLC resulting from the December 2012 coheating test was 133.8 (\pm 1.9) W/K. The two test results obtained 35 months apart with differing research teams differed by < 1%. An independent sample T-test of the 24 hour solar corrected HLCs obtained from both tests showed no statistically significant difference ($P = 0.432$) between the HLCs obtained in each test, this suggests a reasonable level of repeatability in the coheating test in this instance.

Alternative approaches to whole house heat loss

In addition to checking the repeatability of the coheating method on the same dwelling in the field, opportunity also presented itself to cross check alternative methods through the Saint Gobain Energy House project (Farmer *et al.*, 2014; Weaver and Gibson, 2014). At each of the six stages of the retrofit project, blind tests were undertaken independently by the Leeds Beckett University research team and Saint Gobain Reserché. The Saint Gobain team used their QUB (Quick U-value of Buildings) method (Pandraud *et al.*, 2014) and the Leeds team used the coheating test. Due to the unique facility offered by the Salford Energy House, it was possible to perform each test separately and sequentially, under the same controlled external

conditions, something which is not possible to achieve in the field. QUB is a very simple diagnostic method that enables the heat loss coefficient to be calculated over one or two nights. It measures the temperature response during a heating and free cooling period. A level of uncertainty is estimated to be $\pm 15\%$ when performed on a single night which becomes less as the test period is extended (Pandraud *et al.*, 2014). Cross checking of the methods at the energy house showed a much closer fit than expected. Good agreement was found between the results of both testing methods (Farmer *et al.*, 2014). The blind nature of the tests, showed that both methods were able to reliably identify the heat energy transferred through the fabric. The results of the QUB tests suggest there is merit in developing a commercially viable alternative to the coheating test which may encourage more widespread performance checks in the industry.

Other methods, based on in-use monitoring data have also been cross checked with the coheating tests and show comparable results. The Integrated coheating, currently being developed by Leeds Beckett University is of interest if integrated with smart monitoring (Farmer, 2015). The test is a variation on electric coheating that uses the test dwelling's own heating system to provide the heat input, and control of internal temperature, throughout the test. A heat meter is used to measure the space heating energy delivered to the test dwelling; this allows the efficiency of the heating system during the test to be measured. This means that an integrated test has the potential to quantify both fabric and system performance, hence it assesses the dwelling as an integrated system. Initial tests show a reasonable agreement between the heat loss coefficient (HLC) obtained from integrated coheating and the HLC obtained from electrical coheating. Integrated coheating type test will experience many of the same variations as current coheating tests. However, as the provision of heat to the test house during an integrated coheating test is more likely to resemble what is experienced during the dwellings operation, the HLC estimate obtained from integrated tests is more likely to be representative of how the dwelling will perform in-use. As integrated coheating is less resource intensive and can utilise cheaper forms of heating, it has greater potential than electric coheating to be used as a viable commissioning and monitoring test. The importance of measuring the energy delivered for space heating, was something that was previously missing from similar work that did not show the same capability in providing HLC (see earlier work by Sutton *et al.*, 2014). The Integrated coheating, utilising heat meters, represents a considerable change in the potential data that can be extracted during in-use monitoring.

Validity: Aggregating and disaggregating data

Whilst alternative methods of measuring the HLC of a building might hold commercial advantage the real power of using a coheating test to determine thermal performance and disaggregate the building's heat transfer for elements. In particular, to perform an analysis of the empirical heat loss data using the standard definitions of heat transfer coefficients defined in ISO 13789 (ISO, 2007), separating ventilation heat loss as an independent factor.

The prolonged steady state internal environment demanded for the coheating test provides ideal conditions for accurate heat flux measurement to ISO 9869 (ISO, 1994) and detailed thermographic analysis. This disaggregation of the results is crucial when it comes to assessing the performance gap. Rather than simply listing how much the whole house HLC measured exceeds the predicted figure, by splitting both measured and predicted figures into these component values the tests can provide quantitative

information for each building element identifying the specific elements that are responsible for the performance gap. Such work is essential to ensure efforts are concentrated when attempting to minimise the gap. In conjunction with thermal bridging computation, the measured elemental and whole house heat loss values provide a comprehensive assessment of heat exchange and help to close the loop.

Air leakage

Initial tests on a small and varied sample of existing buildings in the UK (Gorse et al., 2014), found some buildings to be so leaky that it would not be possible to perform tests using standard electrical heating equipment. The power required to elevate the whole house to a sufficient temperature above its surroundings would overload and fuse the property's electric supply. This has important implications as structures of this nature cannot be accurately tested using portable electrical heating. In relatively small buildings, air changes rates of $\approx 16 - 29 \text{ h}^{-1} @ 50 \text{ Pa}$ were found in properties that had been previously occupied. Very leaky buildings, such as those with the conditions observed suggest that it would not be possible to adequately heat the whole building during winter without excessive heat input. Aside from the testing discussion, Santamouri *et al.* (2014) suggest that we are freezing the poor in Athens, however, the initial results reported here are a clear indication of the same problem in the UK's colder climates.

Air testing in retrofit properties can be particularly revealing. In similar properties with similar retrofit measure air permeability results can be surprisingly different. In recent studies where floor and edge seals were overlooked improvements were limited ($24 - 20 \text{ m}^3/(\text{h}\cdot\text{m}^2)@50\text{Pa}$). In properties, where attention was given to detail design and workmanship stepped changes from around 19 to 4.73 ($\text{m}^3/(\text{h}\cdot\text{m}^2)@50\text{Pa}$) and 16.77 to 6.43 ($\text{m}^3/(\text{h}\cdot\text{m}^2)@50\text{Pa}$) were achieved (Gorse *et al.*, 2015). Understanding the level of airtightness achieved is a relatively straightforward commercial test. Furthermore, the introduction of a thermal survey during the heating season under depressurisation provides valuable information on the building's behaviour.

Addressing the challenge: Interventions and effects

The tools used to measure the performance are of limited use if not applied in a systematic way. Those that can readily assist with quality assurance can be accommodated within all forms of construction, the more scientific studies should be applied in a manner that suits the situation and care given to the testing regime so that the key issues can be properly measured. There are some notable examples of research that clearly show the step change in behaviour.

The Temple Avenue project (CeBE, 2010) is a typical example of staged intervention demonstrating how improvements can be made to new developments and retrofit projects. At the same time as undertaking the refurbishment of an existing 1930's property to the same thermal and energy performance as two highly energy efficient new-build prototype dwellings the Joseph Rowntree Housing Trust also developed and tested prototypes before producing the final designs for a new 540 home development (CeBE, 2010). This scale of the research does not need to be applied to whole buildings, often it is possible to examine elements in some detail. Work with Knauf Insulation on the effectiveness of different products has offered a lead in this area. An example from a recent study focusing on party wall interventions is shown below. The results clearly show how the intervention of retro-fill blown mineral fibre significantly changes the thermal behaviour of a masonry cavity party wall.

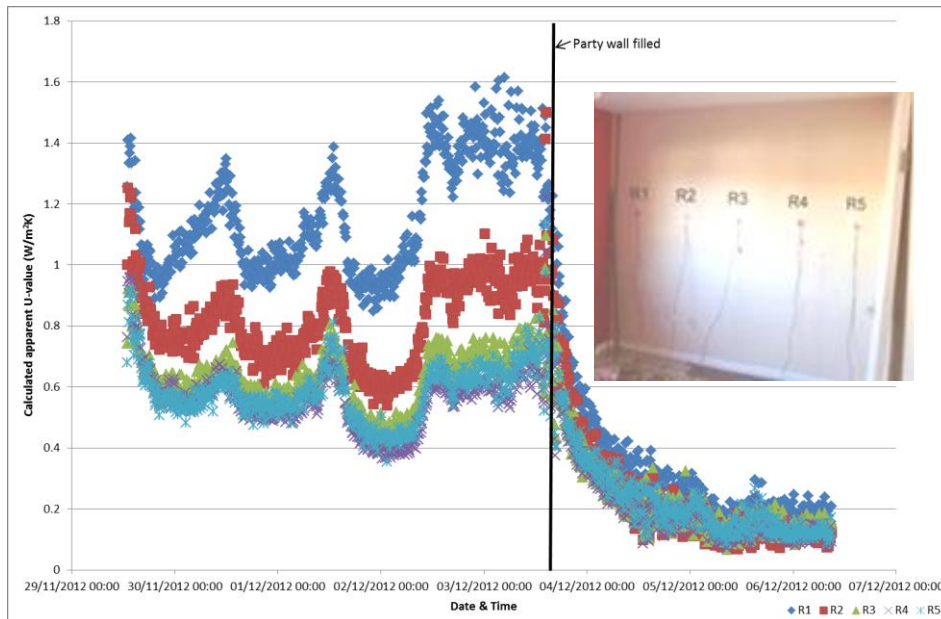


Figure 1: An unfilled cavity party wall exhibiting characteristic signs of thermal bypass and air movement, the full-fill intervention creates a fabric that controls movement and significantly reduces heat loss.

The results show significant improvements to the thermal performance of the wall. Prior to the intervention of full-fill insulation the wall failed to provide an effective barrier to the outside elements. The variability of the heat flow before the insulation fill was introduced suggests that the wall was not effectively sealed and experienced problems due to air infiltration, bypasses and other breaches of the building fabric. The graph (Figure 1) shows how insulation added to existing walls can provide a consistent and performing fabric, offering the desired thermal resistance and creating a separation between internal and external environment conditions.

The Saint Gobain Energy House Project (Farmer *et al.*, 2014) provided a full-scale and staged retrofit to the replica Victorian Terrace. In the Energy House Project, the whole building, which is constructed within a controlled environment, enables the temperature and environmental conditions surrounding the property to be controlled. Different retrofit upgrades were added to the property and three expert teams using multiple methods of measurement analysed the results. The project represents an important point in building performance research; in most other retrofit trials the full retrofit is applied and it is difficult to investigate the individual contribution of the systems that make up the whole. Specifically, the Energy House project provides an example of a systematic and staged approach to the measurement of thermal upgrades. The knowledge gained on the elements and whole building's performance provides a key step forward in understanding the behaviour of a building that is representative of a significant proportion of the building stock in the

The staged elemental changes confirms the interventions contribution to the reduction in the building's heat loss. Under the facility's test conditions greater certainty was achieved and ambiguity, which has previously resulted from trying to compare different houses and house types in variable climatic conditions, was removed. There remain limitations of the test environment, as the conditions are not real, but the approach has advantages. Thus, it was possible to focus more thoroughly on the building changes introduced and measure their impact, and validate the methods.

The Energy House laboratory allowed each thermal upgrade to be exposed to a range of conditions, the same exposure being repeated for each upgrade allowing direct comparison of six upgrades. Standardising the test environment and removing the uncontrollable conditions experienced in the field allowed the research teams to concentrate on the improvements made and the accuracy of the methods used.

Test and measures: Using the tools to improve the construction process

Tools often used during field work are listed (table 1 and 2) and from observations made during their application suggestions are provided on their ability to inform the construction process. In many of the studies reported, detailed photographic and documentary evidence was collected during the construction process. Such information proved useful during building forensics, when attempting to uncover why problems occurred and performance differed from that expected. Such process and construction data is clearly important when identifying the root cause a problem and making improvements to the construction process.

Clearly all the tools discussed are of benefit to understanding building performance, however, for small scale developments, many, such as coheating, are too resource intensive to be economically feasible. Contractors are benefitting from the findings of performance evaluation work and, although it is not yet possible to integrate all of the test methods into the construction process, there are benefits in using some of the simpler tools that have fewer resource constraints.

Table 1: Inspection methods: thermal performance

Field tests and measures	Information gained and suitability to inform the construction process
Photographic and video records (with meta data, for example: date, time, position, elevation, altitude, weather data links)	Chronological record of construction work, identification of materials installed and assembly. Log to ensure material fit as spec and design. Possible to use the information, record in real time using systems such as vrm technology
Survey data temperature, humidity, surface temperature	Identification of consistent and irregularities. Identification of moisture and thermal patterns. Quick laser guided temperature sensors can be used to inspect properties during winter heating. These can be easily accommodated within inspection processes.
Air tightness and smoke tests.	Air change, permeability and leakage detection. Relatively inexpensive, should be used to assess air tightness in new buildings, mandatory for a sample, however there is benefit for greater application.
Thermography (without pressurisation)	Identification of hot and cold spots, indication of cold bridge, moisture and bypass. With the intervention of thermal cameras linked to mobile phone technology the cost of the equipment has reduced drastically and can be used during inspections during winter heating periods
Thermography with air tests, smoke test, bypass detection.	Cold bridging, air leakage, bypass, air circulation paths

Within the research projects already discussed, the performance measurement tools have proved informative in recognising where performance has been achieved and where further work is required. The use of simple tests such as blower doors, supported with thermal cameras or smoke guns to identify air leakage proved useful in identifying problems (Table 1). The blower door, smoke and thermal surveys can be used in all domestic projects. Problems, recognised through simple tests, may be a

result of design failures or poor workmanship. Once the cause of the faults are recognised, through forensic investigation, including the review of design documents, site photographs and site records, the aspect of the construction or design process that requires change can be addressed, becoming the focus of further monitoring.

The heat loss tests and measure remain resource intensive and are economically limited to large scale projects. However, the results of the tests have proved invaluable in recognising performance differences and where buildings have met their design targets. Table 2 identifies the information that can be gained from different tests.

Table 2: Thermal performance tests: heat loss and thermal resistance

Test method	Information gained and suitability to inform the construction process
Integrated coheating: In use whole building fabric and system monitoring.	In-use feedback of building performance – potential constant feedback if integrated with smart technology (HLC), suitable for fabric and service commissioning and in-use efficiency. Potential to provide dynamic, steady state signatures, thermal response and behaviour. Could be used for end of line commissioning test.
QUB Quick U-value of buildings: dynamic energy signature and building response.	Overnight test (HLC), suitable for commissioning test at the end of the build period. Still exploratory, but early indications suggest that this test will be useful in providing a rapid indication of thermal building performance.
Coheating: Heat loss coefficient, also the heated building lends itself to thermography, building survey and forensics	Whole building diagnostics (HLC), element and whole building investigation and prototype fabric testing. Very useful as the base line test to investigate prototypes and new systems. Due to high resource requirements it is economically limited to large scale developments. Beneficial for prototype and product testing, provides ideal conditions for further building forensics.
Heat flux measurements and surface temperature measurement (performed concurrently with coheating)	Elemental performance . The heat flux measurements require the similar controlled conditions to the coheating tests. It is expected that such tests would be used on small samples and prototypes, being too resource demanding for testing all buildings.

CONCLUSIONS

Attempting to close the loop between designed and actual energy consumption in buildings is not an easy challenge; the multifaceted approaches outlined in this paper provide an indication of a sample of tests and methods for measuring thermal building performance. The use of such tools within the practice of construction needs to be better understood. It is clear that there are merits in pursuing methodologies like the coheating test to gain detailed understanding of issues at the same time as ensuring commercially viable tests are developed that can support performance checks. Some tests are resource intensive and their use would be economically prohibitive in the testing of all new homes and retrofits. For prototypes it is essential that developers and contractors understand the performance achieved and reasons for not achieving performance. Once an understanding of what works is gained, then simple checks can be made to ensure that performance conforms with design expectations. The quicker tests such as blower door, thermal surveys and smart energy monitoring provide relatively inexpensive feedback. Further work needs to be undertaken to see how these can be adapted for use as part of process and conformance checks.

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OPERATIONAL EFFICIENCY OF THE UK COMMUNITY ENERGY OWNERSHIP MODELS

Ayi Iboh¹ and Ibrahim Motawa

School of Energy, Geoscience, Infrastructure and Society, Heriot Watt University Edinburgh, UK

The challenges posed by climate change, energy security and man's endless demand and consumption of energy have become a serious threat to human existence. Surmounting these challenges requires an extensive transformation of the current centrally concentrated energy system in most nations, into a people centred and community oriented system. Community Renewable Energy Projects are emerging form of energy governance system that have contributed substantially to a reduction in this global threat generally and in the UK in particular. This paper presents a critical review of literature which examines the different ownership models of Community Renewable Energy Projects (CREPs) in the UK. In addition, the key aspects of these models that enhance their operational efficiency are reviewed in order to establish the connections between a robust ownership model, its attractiveness to the community groups and individuals involved and the overall project outcomes. Three theoretical concepts are employed in the development of a framework that connects groups of effective ownership model indicators to aspects of the model improvement and their impacts on CREPs Outcome. The framework highlights the importance of competent internal management structures, availability of project administration and management expertise and timely external supports for the UK community energy groups as a precursor to organising successful CREPs with optimal performance in line with expected environmental, social and economic outcome.

Keywords: community, renewable energy projects, ownership models, operational efficiency.

INTRODUCTION

The subject of community (local) involvement in Renewable Energy activities is one of the most active areas in energy research today (Walker and Devine-Wright, 2008). Community based activities towards environmental sustainability are not new, although the approaches are different. Emphasis on such activities in present times tends to be more on Community Renewable Energy Projects (CREPs). According to Alvial-Palavicino *et al.* (2011), CREPs constitute an integral part of the overall global micro Renewable Energy (RE) generation program.

The installation of solar panels on the roofs of many private homes and the collectively organised energy projects by individuals or groups of local environmental activists all attest to this fact especially in Europe. The case of Denmark is a typical example, where local authorities promoted the Danish citizen's participation in implementation and ownership of Energy Projects in the late 1970s. At the moment, a quarter of all the electricity consumed in Denmark is from wind energy projects owned by the community (McLaren Loring, 2007). Evidently, 80% of these wind

¹ aai11@hw.ac.uk

energy systems is owned locally through community partnership, putting Denmark as the World's leader in Wind Energy development.

Similarly, Germany is determined to switch to renewable for at least 80% of her total energy demand before the year 2050. So far, more than 13% of Germany's energy consumption is from Renewable sources with the community competing favourably with the big energy companies. Spain on the other hand has recorded a 14% contribution to its total energy demand from renewables. A major setback in the Spanish energy sector (hindering local participation) according to Sáenz de Miera *et al.* (2008) is the prolonged domination and monopolisation of the sector by larger Energy companies. However, there are community owned RE projects in Spain which are unpopular, but legislative instruments are currently underway to promote these projects.

From the UK RE policies point of view, it appears that the UK Energy System is centrally governed in some way. This is because major legislation and policy on Energy issues are till date, the preserve of the Government's Department of Energy and Climate Change (DECC, 2014). That notwithstanding, locally organised energy has delivered substantial amount of Energy to many homes and businesses in the UK. The multiplier effects include reduction of community carbon foot prints that could lead to attainment of UK's carbon emissions reduction targets.

Numerous studies have attempted to define what Community Energy (CE) means (Walker and Devine-Wright, 2008, MacQueen *et al.*, 2001, DECC, 2014), but there are currently no universally acceptable definition for the concept. For the purpose of this paper, a simple definition within the context of citizen's involvement in RE generation, and in line with the UK Department for Energy and Climate (DECC) is adopted. DECC (2014), sum up Community Energy to mean diverse groups and the various responsibilities undertaken by the groups to ensure that local people accept and participate in small scale Renewable Energy projects and also benefit from positive environmental, social and economic outcomes of the project activities. This can be either temporary or permanent group of enthusiastic individuals generating, purchasing, managing energy and or promoting efficient use of energy.

From the above definition, it can be deduced that local participation and leadership in Energy matters is vital to achieving global carbon reduction. This paper therefore reviews key aspects of operational efficiency of CE ownership models and proposes a theoretical framework that sheds more lights on the connections between the importance of a robust ownership, and its attractiveness to the community groups and individuals involved in CREPs and the overall project outcomes.

REVIEW ON COMMUNITY OWNERSHIP OF ENERGY PROJECTS AND MODELS EMPLOYED

Generally, community ownership implies a change in management control, rights, and privileges over an asset, infrastructure, and services from a centrally governed authority to a relatively more decentralised market and people oriented authority in the form of a long, free or short lease. Research on assets ownership indicates that proper local community engagement in ownership and management of public assets can yield positive benefits.

In the energy sector, citizen's ownership of energy projects can be traceable to energy revolution in Denmark and Germany. Prior to this revolution, European Energy policies were designed to foster the fossil fuel dominated Centralised Energy System

(da Graça Carvalho, 2012). Walker and Devine-Wright, (2008) summarised that the different forms of community-led and community based ownership of energy projects are aimed towards establishment of a unique process of energy sector governance that fosters Citizen's participation, acceptance of the projects and creation of awareness on dangers of Green House Gas (GHG) emissions

Since Energy projects are capital intensive (McLaren Loring, 2007) and usually depend on a long supply chain, it is essential to put in place, an organised, structured and in most cases legal system of managing them. Therefore prior to commencement of any REP irrespective of the scale and size, a vehicle for successful project delivery is a necessity. This vehicle usually is a network of professionals, volunteers, interested individuals and investors with a shared vision of getting involved in the planning, organisation, implementation and ownership of Renewable Energy Projects (Walker and Devine-Wright, 2008). Ownership models for setting up rural electrification have been in used in Germany since early 20th century (Shamsuzzoha *et al.*, 2012).

These models are numerous and as such, not all would be covered in this paper, however, the legal models commonly and widely used in setting up energy projects within the UK and other EU states would be identified for this study. The popular forms of partial or full community oriented REP ownership range from an individual's ownership of a solar panel on a domestic building to commercially organised Social Enterprise, Cooperatives, Community Trusts, Housing Associations and Local Partnership with commercial developers. Table 1 below shows some case Community Renewable Energy Projects, their Models of Ownership and other vital project information that is worth mentioning

Table 7: Community Renewable Energy Projects and Models of Ownership

Project/ Location	Cost	Ownership Model Type	Technology	Local membership	Project Benefits
Horshader Wind Project at Dalbeg and Isle of Lewis	Almost £1.9M	Community trust	Wind Technology	More than 80% of local residents	Proceeds used for local transportation system improvement
Hanover Housing Association Wood fuel Project at Fort William in Scottish Highland	Almost £113,000	Housing Association	Woodchip: Froeling Turbomatic 100kW boiler	Elected governing board	Installed system provides affordable heating to 25 unit sheltered housing development for the elderly
Lewes Solar Project at Lewes, East Sussex	Almost £310,000	Partnership	Solar PV	251 members	Affordable energy for community
Westmill Wind Farm at Oxfordshire	£4.6m	Co-operative	Wind	Over 2,000 local members	Supplies energy to over 2,000 homes annually

From above table, it can be argued that local participation, derived benefits, models of ownership and cost of project vary from place to place. These varying features make it difficult to conclude that a particular model is more effective than another in delivering successful CREPs. The various models identified above are critically examined below.

HOW LOCAL PARTNERSHIP, COOPERATIVES, COMMUNITY TRUST AND HOUSING ASSOCIATION MODELS WORK

Partnership has generally been encouraged as a shield for the individual or community group with little or no risk appetite but with ambition, passion and enthusiasm to engage in business. In the Energy sector, partnership as a model of CEP development is common in Germany where limited companies collaborate to set up CREPs (Bonhoff, 2008). The level of control depends on the amount of shares each partner holds. Membership of this form of model can be restricted to the local residents and or external commercial Energy companies; however this model depends on hired external expertise for daily management of project activities. Unlike partnership model where membership is restricted and expertise is sourced externally, the incentives for setting up CREP through the Cooperative Model are different from every other model. The principle of cooperative ownership aligns well with CEP principles of keeping development, operations, ownership and benefits of the project within the community. The model encourages equal rights and opportunity in decision making and profit sharing amongst participants based on one man one voting right.

It is not surprising that the model has been the most adopted and widely employed for community ownership of REP. According to (Willis and Willis, 2012), membership strength of Cooperatives all over the UK is over 900 million while about 90million locals are gainfully employed by these Cooperatives as at 2014. In contrast to Cooperative, that puts the interest of members first, Community Trust (also known as Development trust in Scotland) on the other hand supports local investors and non-investors alike to benefit from the CEPs. It functions as a medium for attracting wider environmental, social and economic CEP gains to the entire community. The model is structured such that no individual or group can lay claim to ownership of this model because daily administration and decision making are preserves of a democratically elected board of trustee (BOT). The last model of ownership identified for this study is the Housing Association. In the UK, a Housing Association is a not-for-profit organisation that acts on behalf of low income group by securing affordable accommodation in Estates managed by the association, and meeting any other special needs of this category of tenants. According to Saunders *et al.* (2012), the law, permits tenants to be accepted into the membership cadre and even governing board of the association through democratic means. Egmond *et al.* (2006) also opined that a well organised board can access loans to execute projects (see item 2, table 1) for the benefits of other tenants in the estates. However, these models have shortcomings which are detailed in the section below

PITFALLS OF OWNERSHIP MODELS REVIEWED AND THE NEED FOR A FRAMEWORK TO ADDRESS THE PITFALLS

Drawing on DECC (2014)'s definition of CREPs, the focus of each ownership model should be to keep the development, operations, ownership and benefits of the CREPs within the community and to also encourage equal rights and opportunity amongst participants, as these are some of the main attractions for local participants. While the Cooperatives model promotes equal rights, opportunity and profit sharing (among many other incentives), above Social Enterprise, Community Trusts, Housing Associations and Local partnership models, it is however criticised for being associated with huge administrative burden (Schreuer and Weismeier-Sammer, 2010). On the other hand, Social Enterprise, Community Trusts, Housing Associations and

Local partnership models are rigid in the area of membership recruitment. They also face difficulties in securing funds (Warren and McFadyen, 2010), planning permissions for CREPs development over and above the lack of capacity to break market monopoly of the Cooperatives model.

Therefore it is important to address these drawbacks by identifying each model's efficiency indicators and the key aspects of the ownership models to be enhanced. There are a number of these indicators that can influence the operational efficiency of CEPOM. These indicators according to (Zhao *et al.*, 2010, McLaren Loring, 2007, Belassi and Tukel, 1996), although not exhaustive are listed below:

1. Competitive Business Case
2. Control over Principal/Agent interest
3. Access to Grants/ Funding for the Project
4. Risk Management Skills/Strategies
5. Identification of Local needs
6. Track records of Directors
7. Knowledge of the Sector
8. Incentive Programmes
9. Extensive Feasibility Studies
10. Project scope definition
11. Procurement approach
12. Site(Land)ownership
13. Project Management expertise
14. Market share
15. Access to industry information/practices
16. Favourable Regulatory Frameworks
17. Expert advice on emerging trends
18. Local membership route/criteria
19. Equipment supply and maintenance
20. Availability of local skills/expertise
21. Contractor selection criteria
22. Project Environment
23. Communication Management

CLASSIFICATION OF COMMUNITY ENERGY PROJECT OWNERSHIP MODELS (CEPOM) ENHANCEMENT INDICATORS

The CEPOM efficiency indicators listed above are further classified into three groups thus: Organisational Management related, Project related and External indicators. One may argue the basis for such classifications; the above classification is based on the aspects of CEPOM enhancement it addresses, although the three groups of classifications are interrelated and depend on each other to be relevant, the impact of each group in enhancing CEPOM's efficiency is unique. For instance, external factors may not necessarily constitute risk to Partnership model as it does to the Housing Association Model. This is because complementary skills, competence and experience in the industry are major considerations in a partnership business relationship. Also, the incentive programme as part of Management and Board of Trustee enhancer can also influence the construction and administration of project operations. It is important

to state that the classification is meant to draw attention of Community Energy Groups (CEG) in the UK to the importance of a formidable internal top management and project team with vested knowledge of external local and global barriers and drivers of effective Community Energy Project ownership. On this premise, the need for the development of a theoretical framework that captures all the indicators and their impacts on the various ownership models is important. It is expected that the framework will be an improvement to the current models deployed for CREPs delivery in the UK. The framework is presented and discussed in the next section

DISCUSSION ON IMPROVEMENT OF COMMUNITY ENERGY PROJECT OWNERSHIP MODELS (CEPOM)

The framework highlights the connections between group of CEPOM enhancement indicators, aspects and CREPs outcomes. The Community Renewable Energy Project outcomes (CREPO) is presented here as the objective of the CEPOM improvement process, while Management and Board of Trustee Structure (M-BOTS), Effective Administration of project Operations (EAPO), Environmental, Social and Economic Impacts (ESEI) are considered as CEPOM enhancement facilitators.

Conventionally, every project is said to be distinctively different based on the peculiarity of its location, client, the project team and so on (Andersen *et al.*, 2006). This is entirely true of CREPs; the risk appetite, administrative procedures and the process of organising start-up funds vary greatly. This theoretical framework therefore is based on the considerations for setting up ownership models that can overcome these challenges. The considerations relied primarily on the owner's, consumer's and investor's interest such as tax exemption, electricity bill reduction, and self-sufficiency; and community benefits like job creation, climate resilience and GHG emission reduction. Although the Cooperative model has overwhelmingly become the most attractive model for organising CREPs in Europe, other models when effectively set up could bring about a more robust model for use with any Renewable Energy Technology and by any community. In particular, the theoretical framework is developed for the enhancement of the UK CREPs ownership models; this is so because the scope of this paper cannot exhaustively capture the concepts and indicators of all the ownership models in use by various developed and developing Nations. The various groups of CEPOM enhancement indicators, aspects of enhancement and expected project outcomes are discussed in subsequent sections.

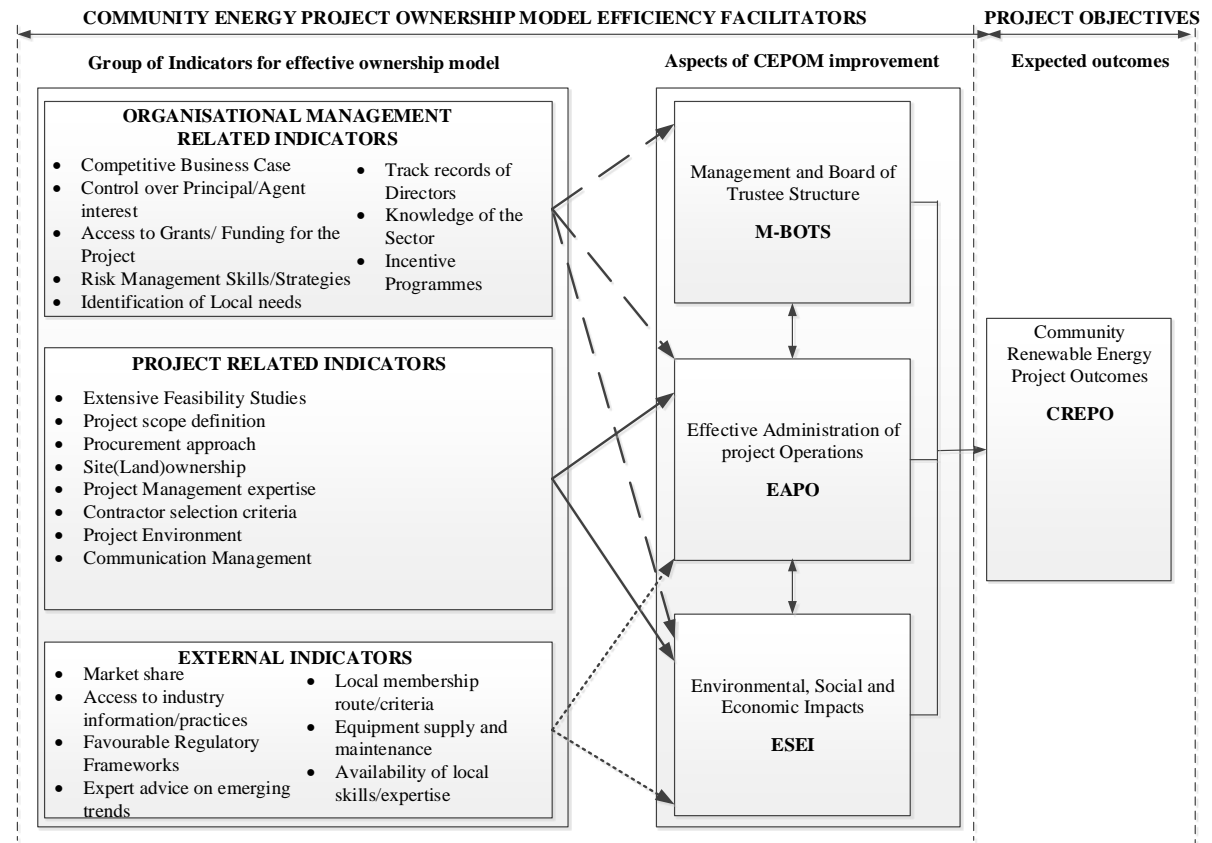


Figure 1 Theoretical Framework for enhancing Models of CREPs ownership

ORGANISATIONAL MANAGEMENT RELATED INDICATORS

Since CE is an emerging energy governance system, the ownership models are vulnerable to internal management failure as a result of an incompetent management and project teams. In addition, failure may be caused by external influences such as lack of adequate technical support, funding, and regulations. CEPOM as an organisational setting for CREP development and management thrives on a formidable and competent top management structure. Although in most CEPs, top managers, shareholders and funders are not part of the daily running of CREP operations, they however have significant power to influence major decisions. The management and Board of Trustee of the model therefore must show the will power to check principal/Agent interest among top managers and ensure the project is profitable, financially stable with a substantial share in the CE market. Effective management of project operations and capacity to deal with bureaucratic obstacles is also an important attribute deserving of the top managers. Above all, members of the model are expected to be experts in Renewable Energy Sector with essential skills to develop a business case that emphasises economic, social and environmental goals.

PROJECT RELATED INDICATORS

Although the focus of this paper is mainly on the operational efficiency of ownership model (operational phase), it is equally important to acknowledge that if the scope is not defined, or project completed on time and according to specification and purposes intended, the operational activities cannot commence.

The group of indicators for determining successful project delivery according to Bowen *et al.* (1997) varies based on the technical features of project, the project

environment, team and stakeholder's expectation from the project. The choice of a contractor in a conventional construction project is determined by the contractor's competence in delivering the project within a specified cost, time and expected quality (TCQ). On the contrary, CREPs in addition to TCQ also emphasizes that the project must be environmentally friendly and dependant, socially cohesive and economically viable and sustainable for the locals.

The construction process of CREPs comprises a long supply chain of equipment manufacturers, installers, designers, developers and so on. It is also the most important phase of the project as soon as planning permission and funding is secured. Therefore any involvement of locals in this phase will place heavy demand on local skills and the respective ownership model top management. It is the responsibility of the top managers of these models to ensure there is sufficient technical, administrative and project management capacity to undertake CREPs.

EXTERNAL INDICATORS

This group of indicators have indirect, yet very critical impacts on the functionality of CEPOMs and the performance of CREPs in the UK. The CE sector is a new and emerging sector that depends largely on external grants and funds for its programmes, this means that for the market to be fully established and sustained, the sources of supply of grants and funds must be guaranteed, because a prolonged cut in cash flow can render the project moribund. Moreover, increasing technology innovations, national regulations, legislations and changing market conditions have long term implications on the survival and outcome of the project.

Although full local ownership of the project is emphasised in CEP, the increasing project demands highlighted above have compelled the local community's dependence on external inputs to fully achieve project goals.

However, whilst the inputs of external commercial and technical experts is appreciated in promoting CEPs, the gradual diffusion of CEPOM with the practices, methods and procedures of these external aid providers must be checked. It is equally important that both local members of the Energy Groups and non-members alike have their opinion respected and considered by top management.

ASPECTS OF CEPOM IMPROVEMENT

The aspects of CEPOM improvement (Management and Board of Trustee Structure – M-BOTS, Effective Administration of Project Operations – EAPO, and Environmental, Social and Economic Impacts – ESEI) may be similar for all models. The importance of each indicator (Organisational Management related, Community Renewable Energy Project related and External influences) varies from one ownership model to another. It is expected that Community Energy Groups (CEG) will make necessary adjustments (introduce local conditions congruent to the project) into their chosen model before organising CREPs. However, the framework is only a guide to CEG on what aspects of the model to prioritise. The practicality of the framework would be further validated as the research progresses, it is expected that many more indicators and aspects of CEPOM improvement maybe identified from survey and interviews to be conducted in the coming months.

CREP OUTCOMES

CEP underpinned by sustainable long term investment plans could scale up local businesses and investments. In addition, the returns on investment from the projects

are used for projects to meet other community needs other than energy over and above development of local skills and job creation. It is also important to clarify that the key aspects of the ownership models can only be enhanced when the various enhancement indicators are holistically considered and responded to by the top management

CONCLUSION

This paper proposes a theoretical framework to both local energy groups and commercial developing partners engaged in or about to start up a community renewable energy project in the UK. Drawing on key aspects of operational efficiency of CE ownership models, the paper sheds more lights on the connections between, a robust CREP ownership model, its attractiveness to the community groups involved in CREPs and the overall project outcomes. One of the most significant findings to emerge from this study is that for any local energy group to effectively organise an energy project that can deliver expected benefits to all the stakeholders, the type of ownership model and internal management capacity must be robust.

The second major finding was that availability of project administration and management expertise and timely external supports for the UK Community Energy Groups is lacking in current models of CEP ownership, thereby limiting optimal CREP performance in line with expected environmental, social and economic outcome. This paper is part of an ongoing PhD research; therefore further work will be focused on collection of primary data through distribution of online questionnaire and face to face interview of CE experts in England and Scotland. The initial data analysis will be based on descriptive statistics followed by a more comprehensive factor analysis, analysis of variance – ANOVA. Based on flexibility and compatibility with a range of variables, Standard Multiple Regression analysis will be employed to model aspects of different CEPOM that enhances or undermines CREPs economic, social and environmental performance.

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CONCEPTUALIZING SUSTAINABLE RETIREMENT VILLAGES IN AUSTRALIA

Xin Hu¹, Bo Xia², Martin Skitmore³ and Laurie Buys⁴

^{1, 2 and 3}*School of Civil Engineering and Built Environment, Queensland University of Technology, Gardens Point, Brisbane QLD, 4001, Australia*

⁴*School of Design, Queensland University of Technology, Gardens Point, Brisbane QLD, 4001, Australia*

The Australian ageing society with baby boomers reaching retirement age has placed a lot of pressures on housing services. The retirement village is increasingly accepted as a suitable living arrangement for older people. Ecological theory of ageing emphasizes a match between environment and older peoples' competences. As one response to this, creating village environment in a sustainable way is on the agenda. However, it is not very clear what kinds of sustainable features should be incorporated within the village environment to fit residents' competences, in particular given that baby boomers who have unique requirements have become the main potential customers. In present paper, a sustainable retirement village framework is proposed by building on ecological theory of ageing and triple bottom line. A two-step inductive reasoning research method is adopted in this conceptualization process. The proposed sustainable retirement village framework contains four domains, including senior-oriented basic settings, financial affordability, age-friendly social environment and environmental sustainability. These four domains are interrelated, and a sustainable retirement village stresses a dynamic balance between different domains. This proposed framework not only gives implications for village developers on creating a suitable village environment to better accommodate residents, but also paves the way for future studies on housing older people in an age-friendly manner.

Keywords: sustainable retirement villages, ecological theory of ageing, triple bottom line, Australian baby boomers.

INTRODUCTION

The ageing population has become an established trend in Australia, and this trend will accelerate over next a few decades with the predicted proportion of the aged 65+ being 18.3-19.4% in 2031 (Australian Bureau of Statistics 2013). This demographic ageing has posed a lot of pressures on housing services. These pressures are becoming heavier, given that baby boomers with unique requirements and more expectations than other generations are entering into retirement (Ozanne 2009).

The retirement village is one of the living arrangements of older Australians. It is an institutional environment where accommodations, services, and facilities are tailored to satisfy residents' requirements (Gardner *et al.* 2005). It has been accepted as a viable living option for older adults, accommodating around 5 percent of older Australians (Xia *et al.* 2015). Given the fast-growing ageing population as well as the

¹ huxincqu@gmail.com

increasingly accepted village lifestyle, it is becoming more popular with the estimated penetration rate reaching 7.5-8 percent in next few decades (Jones Lang Lasalle 2008).

To better accommodate residents, the village environment should be fit with residents' competences. Nevertheless, some villages have failed to meet residents' needs in terms of affordability, life-style and ergonomic needs (Gardner *et al.* 2005). This situation may exacerbate given that baby boomers' unique features are redefining Australian retirement village development models (Wright *et al.* 2014). To address this issue, delivering "sustainable retirement villages" is a promising approach (Xia *et al.* 2015). A sustainable retirement village offers residents a suitable living environment where residents' social, economic and environmental needs are well satisfied (Xia *et al.* 2015). Older people expect to live in a sustainable environment such as sustainable social and physical living environment and housing affordability (Pillemer *et al.* 2011), and they can make contributions to making their living community sustainable (Ritchie 2000). For village residents, they also expect village developers to provide a sustainable village environment, and they have played positive roles in sustainable village development such as renewable energy utilization (Xia *et al.* 2014).

However, "sustainable retirement villages" is novel concept which has not been widely explored. Previous explorations, such as Xia *et al.* (2015) and Zuo *et al.* (2014), are case studies and merely suggest a concept. They do not clearly point out what kinds of sustainable features should be contained within a retirement village environment to fit residents' competences, especially competences of baby boomers. Thus, this study aims to propose a sustainable retirement village framework to well response to Australian baby boomers' competences on the basis of ecological theory of ageing and triple bottom line.

THE ECOLOGICAL THEORY OF AGEING AND ITS IMPLICATIONS ON THE RETIREMENT VILLAGE DEVELOPMENT

Effects of environment on individuals' wellbeing are well recognized. In the specific field of Gerontology, ecological theory of ageing is adopted to explore the issue of person-environment interaction in old age. It indicates older adults' behaviours are the function of their competences and the environment (Lawton 1977). Importantly, older adults' competences and the environment should be in balance with each other, and too much or low environment press (environmental stimuli that are behaviour-activating to individuals) imposed on older people can result in maladaptive behaviours (Iwarsson, 2005; Lawton 1977).

The competence represents the nature of a person such as the physical and mental health conditions and cognitive states. It is the abilities of an individual to function (Iwarsson, 2005). Competence varies from low to high. Lower competence results from declining physical and psychological conditions of older people. The environment means the social-spatial surroundings where older adults live (Lawton 1977). It is classified based on its strength, ranging from weak to strong. Different combinations of competence and environment mean different behavioural outcomes (Iwarsson, 2005; Schwarz, 2012). An older adult with low competences exposing to a strong environment can result in negative impacts on his/her well-being. In this sense, his/her living environment should be adjusted to be in balance with his competences.

The implications of this theory on the development of retirement villages are various. In particular, the two variables, residents' competences and the village environment,

should be in equilibrium with each other to ensure person-environment congruence. To achieve this, understanding residents' competences is the foundation. Given that baby boomers are entering retirement and have become the main potential customers, it is meaningful for village developers to create a village environment that can be in balance with their competences.

RESEARCH METHOD

The research method of inductive reasoning is adopted to conceptualize "*sustainable retirement villages*". Inductive reasoning is utilizing observed data to infer theoretical concepts and patterns (Bhattacharjee 2012). The conceptualization process is on the basis of ecological theory of ageing and triple bottom line. Two steps are contained in the inductive reasoning, including identifying Australian baby boomers' competences and sustainable features inferring.

First, literature review is adopted to identify Australian baby boomers' competences. Exploring baby boomers' competences is a hot research topic in Australia, such as Quine and Carter (2006) and Taylor *et al.* (2014), given that this cohort is entering retirement and has had profound effects on the Australian society. Literatures are searched and collected from previous academic studies and government reports. Second, sustainable features inferring depends on the identified Australian baby boomers' competences. Corresponding responses to the identified competences are well suggested from the perspective of triple bottom line. These responses constitute the main characteristics of sustainable retirement villages. Through this process, a conceptualized sustainable retirement village framework is proposed.

THE COMPETENCES OF AUSTRALIAN BABY BOOMERS

Baby boomers have the general features of older people. In addition, baby boomers differ from prior generations significantly. For instance, they are healthier, more active, better educated and living with higher expectations than their parents (Quine and Carter 2006). Based on literature review, the main competences of Australian baby boomers are measured from four aspects, including basic features as older people, financial, social and environmental competences.

In general, baby boomers experience natural changes as older people in terms of physical and psychological aspects such as declining mobility abilities. The village environment should well response to these changes, such as easy access design and basic services provision. In addition, baby boomers' adaptability to a new environment is declining. The retirement village is an institutional environment which means baby boomers live with village rules and regulations and staff behaviours (Stein and Morse 1994). Their declining adaptability to the village institutional environment should be well considered in village daily management and operation.

In financial aspect, financial security and the accessibility of affordable services are core concerns of baby boomers in later life (KPMG 2009). Usually, boomers are wealthier than their parents with more disposable capitals entering into retirement (Andrews 2001). Nevertheless, some boomers do not have sufficient money for their retirement, and therefore have lower levels of financial security (Humpel *et al.* 2009; Snoke *et al.* 2011). Reasons can be diverse, such as financial irresponsibility, less inheriting from parents, and in needs of financially supporting family members (Quine and Carter 2006). Their main retirement income sources are government pensions and allowances, which may be insufficient (Jefferson and Preston 2005).

In terms of social aspect, keeping current lifestyle is a common expectation of baby boomers. First, baby boomers expect the social environment of independency, security and privacy (KPMG 2009). Second, baby boomers expect the accessibility of support and services, especially health related. This is because that some of them suffer from various health issues due to unhealthy lifestyles (Humpel *et al.* 2010). This results in the broadened range and intensity of support and services (KPMG, 2009). In addition, baby boomers expect to retain their social networks, such as keeping close connections with family members and friends (Quine and Carter 2006). Moreover, boomers value social participation. The majority of them prefer participating in activities and continuing to be active members of their community (Quine and Carter 2006; Taylor *et al.* 2014). Furthermore, baby boomers have high expectations on their development after retirement, and they also expect to access valuable information in later life (KPMG 2009).

In environmental aspects, older people usually consume more energy owing to their lifestyles (Yamasaki and Tominaga 1997). Baby boomers are concerned about energy consumption and expect their community to be environmentally friendly (Barker *et al.* 2013; Quine and Carter 2006). Thus, the development of retirement villages for baby boomers should take environmental sustainability principles into account to satisfy their accommodation preferences (Wright *et al.* 2014).

A RESPONSE TO THE COMPETENCES OF AUSTRALIAN BABY BOOMERS: THE PERSPECTIVE FROM PROVIDING SUSTAINABLE RETIREMENT VILLAGES

Why offering the retirement village with sustainable features is a promising solution?

According to ecological theory of ageing, retirement villages designed for baby boomers should well response to their competences. Besides the basic features of baby boomers as older people, other three competences in social, economic and environmental aspects can be responded well by this kind of retirement village environment which is designed based on principles of triple bottom line (Xia *et al.* 2015). This is because that triple bottom line, in the living environment field, means offering a comfortable standard of living, reducing environmental impacts and achieving affordability (Maliene and Malys 2009; Plaut *et al.* 2011). Figure 1 depicts how triple bottom line can well response to baby boomers' competences.

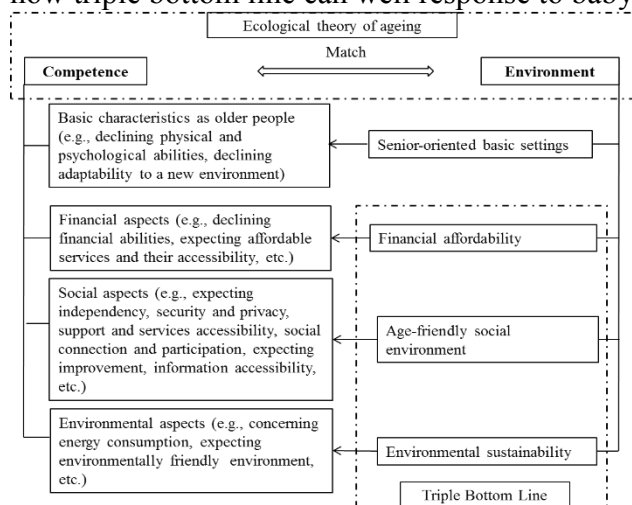


Figure 1: Triple bottom line as a response to the competences of Australian baby boomers

The proposed conceptual framework of sustainable retirement villages

In general, a sustainable retirement village enables to meet its residents' social, financial and environmental requirements besides their basic needs as older people. Figure 2 shows the four domains of the proposed sustainable retirement village framework, including senior-oriented basic settings, financial affordability, age-friendly social environment and environmental sustainability.

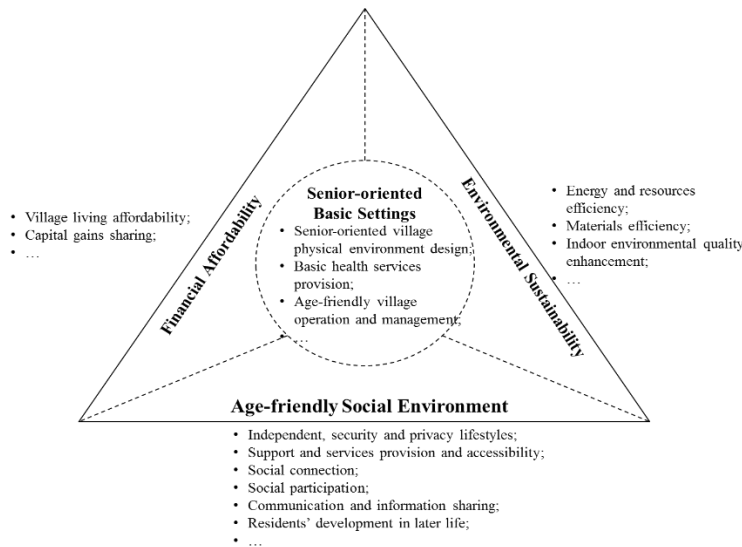


Figure 2: The proposed sustainable retirement village framework

Senior-oriented basic settings

To satisfy residents' basic needs as older people, senior-oriented basic environmental settings are essential, including village physical environment design following the code of design for older people, basic health services provision, and resident-centred village operation and management.

First, the design of the village physical environment should be senior-oriented through following the code of design for older people. This can refer to various aspects, such as village location selection (e.g., near the public transport service), on-site facilities range and their accessibility, village outdoor spaces design (e.g., barrier free design), village buildings and dwellings design (e.g., accessibility), and village natural environment (e.g., beautiful scenery around and qualified air conditions).

Second, it is necessary to make basic health related services affordable and accessible for residents. This is given that the need for health services increases with age owing to the declining health conditions of people in later life.

Third, the operation and management of villages should be resident-centred. Given the institutional feature of retirement villages, village developers should tailor village rules and regulations carefully to avoid creating pressures for residents (Grant 2007), and village managers should be helpful and their behaviours should be age-friendly.

Financial affordability

Financial affordability is an important expectation of baby boomers. For sustainable retirement villages, it refers to village living affordability and capital gains sharing.

First, village living affordability means residents with different socio-economic backgrounds can afford their village life (including the entry contribution, ongoing costs and departure fees) without compromising their future financial needs. Though sustainable retirement village living usually means high costs for residents,

affordability is possible through various ways, such as using practices which do not significantly increase additional costs but bring benefits to residents (Zuo *et al.* 2014).

In addition, capital gains sharing is another important aspect of financial affordability. Capital gains are the added value of resale their village units when residents leave their village. Capital gains sharing ensures more financial resources available for residents for the next accommodation transition.

Age-friendly social environment

The age-friendly social environment is an important part of sustainable retirement villages. It refers to independent, security and privacy lifestyles, support and services provision and accessibility, social connection, social participation, communication and information sharing, and residents' development in later life.

First, a sustainable retirement village should meet residents' needs on independence, security and privacy. Independence means residents can deal with their village affairs by themselves. In this sense, it is the residents who play dominate roles in their village life, and the choice is theirs. To keep independence, measures, such as suitable services delivery patterns and environment settings, are suggested (Haak *et al.* 2007). It also should be noted that to prompt a long-term independence, a short-term compromise on independence is essential at some times. Security refers to both individual security and the environmental security. The individual security focuses on residents' health conditions and financial safety, and the environmental security means providing a safe social and physical environment (Nathan *et al.* 2014). Moreover, it is an unwritten law to respect resident's privacy. Privacy respecting can be achieved by ways such as appropriate village design.

Second, a sustainable retirement village offers residents an appropriate range of support and services to maximize their benefits without exceeding their financial capabilities. The range of support and services should be tailored based on residents' preferences and needs to avoid paying additional costs for support and services that they do not use and do not want to afford (Nathan *et al.* 2013). In addition, the support and services should be provided within residents' walking instances and easy to reach, as residents are sensitive to distance and use support and services that are convenient to them most frequently (Krout *et al.* 2000; Nathan *et al.* 2013).

In addition, a sustainable retirement village promotes residents' social connection by offering them opportunities of contacting with friends, neighbours and family members. To achieve this, diverse measures can be adopted, such as organizing village activities, presence of facilities and communal spaces within villages and making them easy access, encouraging visiting of family members and friends, encouraging services and products exchanges among residents, and techniques assistances (Buys 2001; Nathan *et al.* 2013).

Moreover, social participation in sustainable retirement villages refers to the provision of social participation opportunities, residents' active involvement in activities and village community affairs. First, it is necessary for village developers to provide residents with the chances of social participation. This is usually achieved by organizing village activities. Social Ecological Model suggests that old adults' activities participation is impacted by personal factors, social/organizational factors and physical environment factors (Zimring *et al.* 2005). For personal factors, health related assistances should be offered to improve residents' healthy conditions so as to enhance activities participation levels. For social/organizational factors, village operators should tailor their organized village activities based on residents' interests

and keep activities information informed. In terms of the physical environment, factors, such as village aesthetics, fewer physical barriers within the neighbourhood, and facilities provision, positively affect residents' activity participation (Joseph *et al.* 2006; Nathan *et al.* 2013, 2014). In addition, a sustainable retirement village should offer residents opportunities of playing active roles in the village affairs instead of just passive recipients, such as helping organize activities, being an active member of village resident committees and joining in the decision-making that closely relates to their interests.

Furthermore, informing residents with what is happening and what will happen within villages is also important (Xia *et al.* 2015). A sustainable retirement village should have an unimpeded and two-way communication and information sharing channel. The principles of information provision to older people include relevance and access (Everingham *et al.* 2009). Thus, village staffs should identify what kinds of information are valuable for residents (relevance), and then transmit them to residents in effective ways (access). In addition, residents should be encouraged to give feedbacks on their village life and give suggestions to village managers to help villages' sustainable improvement.

At last, life-span developmental psychology indicates that the need for development is still an important theme in later life and growth can occur throughout life span. A sustainable retirement village should offer its residents ample opportunities to grow and develop. For instance, activities and facilities provision can help residents develop new interests, obtain skills and knowledge that they do not have previously. In addition, offering classes/courses is also a useful way of promoting residents' development in later life.

Environmental sustainability

The retirement village industry should take responsibilities of environmental sustainability given that older people consume more energy (Kronenberg 2009). For sustainable retirement villages, environmental sustainability refers to energy and resource efficiency, materials efficiency, and indoor environment quality enhancement. Its aim is to reduce the negative impacts of the village development and the village built environment on the natural environment and residents.

Energy efficiency means energy consumption reduction. This not only decreases greenhouse gas emissions, but also helps enhance residents' capability of financial affordability (Zuo *et al.* 2014). A sustainable retirement village should develop strategies to reduce energy consumption, such as taking full use of sunlight through suitable unit position and window orientation, energy-efficient construction materials selection, and the application of renewable energy consumption techniques (Zuo *et al.* 2014). In addition, paying for the daily consumption of resources (e.g., water and electricity) is a main part of residents' ongoing costs. To reduce resources consumption so as to make village life more affordable, resources saving approaches, such as water-saving fixtures installing, are encouraged to be adopted.

Materials efficiency means green materials selection in village design and construction stages. The selected construction materials should be recyclable to protect environment (Barker *et al.* 2013). In addition, the selected materials should be not harmful to residents. Moreover, the materials selection should also take the features of residents as older people into account (Zuo *et al.* 2014). For instance, the selected window materials should ensure heat loss minimum in cold days to offer residents warm environment.

It is also of great importance to provide a high quality indoor environment for residents to ensure their health and comfort as they spend most of their time indoor (Lee *et al.* 2011). The high quality of indoor environment mainly contains three aspects, including high indoor air quality, suitable thermal quality and appropriate lighting quality.

DISCUSSION: FEATURES OF THE PROPOSED SUSTAINABLE RETIREMENT VILLAGES FRAMEWORK

This proposed sustainable retirement village framework has three features, including interrelated domains, a balance between different domains and a dynamic system.

Interrelated Domains. The four domains contained in this framework are interrelated. First, senior-oriented basic settings is the foundation of this framework, and other three domains are developed on the basis of it. Second, changes in certain domain will result in corresponding chain reactions in other domains. For instance, inappropriate village physical environment design can negatively impact residents' social participation. This further increases energy and resources consumption as residents will spend more time in their own home instead of outside, which can add additional costs. Third, different aspects in each domain are also interrelated. For instance, in the age-friendly social environment domain, more village activities information accessibility results in higher levels of social participation.

A Balance Between Different Domains. It is impossible to make all the four domains optimal at the same time due to some potential conflicts between them. For instance, adopting environmental sustainability measures can result in relatively high costs of village living for residents in the short-term run. Sustainable retirement villages pursue a balance between different domains to make an overall optimization for residents.

A Dynamic System. Both residents' competences and the village environment change over time. A sustainable retirement villages reflects the two dynamic processes, and stresses a dynamic fit between residents' competence and the village environment.

CONCLUSIONS

The sustainable retirement village is becoming increasingly popular in Australia. In this study, a sustainable retirement village framework is proposed to well response to the unique competences of Australian baby boomers. The proposed sustainable retirement village framework relies on ecological theory of ageing and triple bottom line, and it contains four domains, including senior-oriented basic settings, financial affordability, age-friendly social environment and environmental sustainability. These four domains are interrelated, and a sustainable retirement village emphasizes a dynamic balance between different domains. The proposed sustainable retirement village framework will give implications on the future retirement village industry development as well as paving the way for future studies on housing older people in an age-friendly manner.

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GREEN CAMPUS INITIATIVES AS PROJECTS: CAN CREATING CONDUCTIVE INTERNAL UNIVERSITY PROJECT ENVIRONMENT A KEY TO SUCCESS?

Pantaleo M. D. Rwelamila and Neha Purushottam¹

University of South Africa, Johannesburg, South Africa

Green campus initiatives are becoming integral part of modern day's university systems. However, their management remains slow, cumbersome and limited scope process. Review of related literature suggests that the effective and efficient management of these initiatives require incorporation of project management (PM) principles and thus the need to establish a framework to manage green campus initiatives as projects. Hence the existence of sub-processes likes initiation, continuous coordination, control and ending of green projects. These green campus initiatives (projects) should be part of university strategic management system. In the light of this background, an attempt is made in this paper to describe how to apply project management framework within the University system. The central argument in this paper is about Universities moving away from traditional approaches in embracing green initiatives to establishing a formal process where a sequence of tasks is developed with clear defined objectives and a defined start and end event. It is further argued that the success of any green campus project depends on performing PM professionally. The paper provides an initial framework for implementation of green campus project in contemporary higher education institutions.

Keywords: Green Campus initiatives (GCI), university strategy and environment, sustainability, managing by projects.

INTRODUCTION

Impacts of climate change are increasing and so is the seriousness of the green initiatives. Universities are contributing in the process of environmental sustainability through knowledge creation, green campuses and by advising communities. However, many green campus initiatives either do not reach their full potential or remain challenged by their inefficiencies. A closer look at the literature suggests that besides financial, organizational, process related barriers, major issues like misunderstanding of university culture, lack of flexibility, dynamism, openness and absence of adaptive process are influencing pace of green campus initiatives. Review also indicates that there is a need for an effective and efficient green campus management system and establish a need to look at these initiatives as projects and to create a conducive environment for green campus projects.

This paper is a conceptual paper which is developed with an objective to look at green campus initiative (GCI) management from the perspective of project management philosophies. The aim of this paper is to bring attention of university management towards the utility of project management in addressing challenges faced by

¹ purusn@unisa.ac.za

universities in embracing sustainable green campus initiatives. In the light of these objectives and aims, this paper argues that (a) green campus initiative (GCI) should be seen as a programme with a plethora of projects and (b) Universities should attempt to create a conducive internal environment to ensure success of GC projects. This paper strongly argues that management of green campus initiatives projects should be part of university strategic portfolio.

The first section starts with an introduction of green campus initiatives in the higher education environment. The second section examines the literature on the barriers to green buildings and green campus in higher education institutions. The third section identifies the green campus initiatives at the universities display characteristics of a project and attempts to explore the way GCI can be envisioned at higher education level. Fourth section covers the application of the framework through adopting project management approaches and tools in building conducive university environment for green campus projects. The final section concludes by discussing step by step process to create conducive environment for green campus initiatives (projects).

GREEN CAMPUSES: A GROWING TREND

In the light of growing complexity in environment, society and technology, the issues of climate change and environmental sustainability has gained attention of various social and business institutions (Filho 2000; Stephens, Hernandez, Roman, Graham and Scholz 2008). This trend has posed new demands for contribution from the higher education institutions as universities are considered critical in leading radical change and development (Bloom, Canning and Chan 2005). Universities have started integrating environmental sustainability initiatives in education, research, university operation and administration (Jabbour 2010). Green campus initiatives include management of green buildings, energy, water, food, transportation, purchasing, waste and sustainable landscaping (Calder and Dautremont-Smith 2009). Realization of universities' contribution in degradation of environment through their operations has resulted in the emergence of green campus initiatives (Jain and Pant 2010). The investment in building green campuses was identified most promising due to its highest and the most long lasting impact (Richardson and Lynes 2007).

GREEN CAMPUSES AND ITS CHALLENGES

Literature indicates that the universities have attempted to create green campuses by incorporating environment management system in the university settings. However, these changes remain away from reaching their full potential of systemic transformation (Sharp, 2002). The progress of universities in becoming green is influenced by various challenges and barriers and addressing them will facilitate the pace of progress (Owens and Halfacre-Hitchcock 2006).

Various researchers (Dahle and Neumayer 2001; Richardson and Lynes 2007; Clarke and Kouri 2009; UNIDO 2011) identified several factors which broadly related to physical, environmental (business), financial, informational, attitudinal, managerial and organizational categories. However, due to space limitations, it is not possible to discuss it in detail. Researchers like Sharp (2002) believe that if green campus initiatives are developed with an understanding of true university culture, flexibility, dynamism and openness and implemented through an adaptive process, they will be more successful than the initiatives inheriting the rigidity of university structure.

If we summarize the reviewed literature on barriers so far, it emerges that there is a need of a green campus management system which can manage complexity,

dynamism, change and diverse stakeholders. It is interesting to note that project is defined as transitory and dynamic organization (Shenhar, 2001). Moreover, the ability of project management in handling dynamic environment, transitory activities, and in collaborating with the multiple stakeholders is beyond any doubt (Yiu 2008).

GREEN CAMPUS INITIATIVES AS PROJECTS

Universities are project based organisations (PBO) and they have been like that from time immemorial. It could be argued that projects and portfolios of programmes ranging from training to research in universities normally have clear starts and clear ends, they consume resources and they are unique which fully qualify them as temporary social coalitions (Dinsmore 1999). These projects and programmes remain central to the university business and are part and parcel of university goals and objectives. Hence conceptualizing, planning and implementing green campus initiatives (GCI) as projects and portfolios of programmes should be a natural fit to universities. The starting point for universities to implement green initiatives successfully is to start thinking differently. In order to address the above challenges and to sustain the green movement impetus, universities need to avoid random processes which characterized early green initiatives (Sharp 2002), to give green campus initiatives strategic emphasis and to manage these initiatives parallel with typical university core businesses of training and research.

Using Morris and Jamieson's (1997) conceptual model on corporate strategy, it could be strongly argued that any university strategy is a means to realize its goals and objectives. This strategy, according to Morris and Jamieson (1997) is then typically operationalized at a university strategic business unit (SBU) level (colleges or faculties, schools and departments). Expansion of this approach helps to understand traditional strategic initiatives which are often clustered into disciplines - for certificates, diplomas, degrees (knowledge-base-offerings) and respective research deliverables as portfolios of programmes and projects for implementation. Green campus initiatives need to be formally embraced by university authorities at university strategic business unit (SBU) level parallel with knowledge-base-offerings and research as projects and portfolios of programmes. If green campus initiatives become part and parcel of university goals and objectives - as part of university strategy, then it can reflect into programme or project level implementation (where you will have knowledge-base-offerings, research and green campus initiatives all at parallel level). In practice within the university, projects and programmes (which will include campus green initiatives) will be tools for university strategy to be implemented and it is important to understand its implementation.

Looking at university strategic management through Johnson and Scholes's (1997) lenses, it could be argued that university strategic management is fundamental, wide spread with long term implications but also ambiguous and complex. Normally strategic planning process is organized but it also has dynamic elements (Morris and Jamieson 1997). Application of "*emergent*" view of strategy (Mintzberg and Waters 1984) allows consistent appraisal of outcomes and addressing of emerging challenges and thus ensures flexibility and informality. It can also be argued by taking a leaf from Grabher's (2002) work that the interaction between green campus projects or programmes and the university's strategy may be both "*deliberate*" and "*emergent*" depending on various phases of planning and implementation. However, Morris and Jamieson (1997) argued that the role of project management in implementation is ambiguous, though Office of Government Commerce (OGC) (2003) strongly

supported a growing view (at least in the United Kingdom) that 'change' projects (like campus green initiatives) are really managed best by programme management than by project management (Bartlett 1998; Partington, Pellegrinelli and Young 2005).

The fact that universities are Project Based Organisations (PBOs) by virtue of managing strategic initiatives which are often clustered into disciplines - for certificates, diplomas, degrees (as knowledge-base-offerings) and respective research deliverables leads the authors to believe that structuring green campus initiatives into project will be a direct fit to what a typical university is competent to manage. It is therefore assumed that by conceptualizing green campus projects, by understanding university management model and the position of green campus programme and projects, one will be able to see how they fit together.

It should be emphasized, according to Morris and Jamieson (1997) discussed involvement of senior management w.r.t. issues related to control over expenditure and action. Researchers (McElroy 1996; Broner, Ruckert, and Walker 2002) emphasized the role of senior management in ensuring success of project management in strategy implementation. The role of senior management becomes important considering current good governance practices which require formal alignment between business, portfolio, programme and project plans, and transparent reporting of status and risks to the Board and in this case the University Council [Association for Project Management (APM) 2004].

Managing green campus programmes and projects parallel with other traditional programmes and projects will become a norm within the university and through university policy this combination will be formalized allowing academics and non-academic staff members to get fully involved in implementation processes. Artto and Dietrich (2004) outlined many approaches to manage the strategic portfolio-project linkage in multiple project environments. Similarly, Grundy (1998) also suggested ways (like scenario planning, force-field analysis, stakeholder analysis, and "attractiveness/implementation difficulty" analysis) to integrate portfolios, programmes and projects with corporate strategy. Therefore, it is expected that the decision to implement green campus initiatives as projects and portfolios of programmes will, in fact, motivate universities to develop formal approaches for creating and managing strategy via campus green portfolios, programmes, and projects aligned with university business strategy. Hence Morris and Jamieson's (1997) model to integrate university business strategy with green campus portfolios will be followed as indicated in Figure 1.

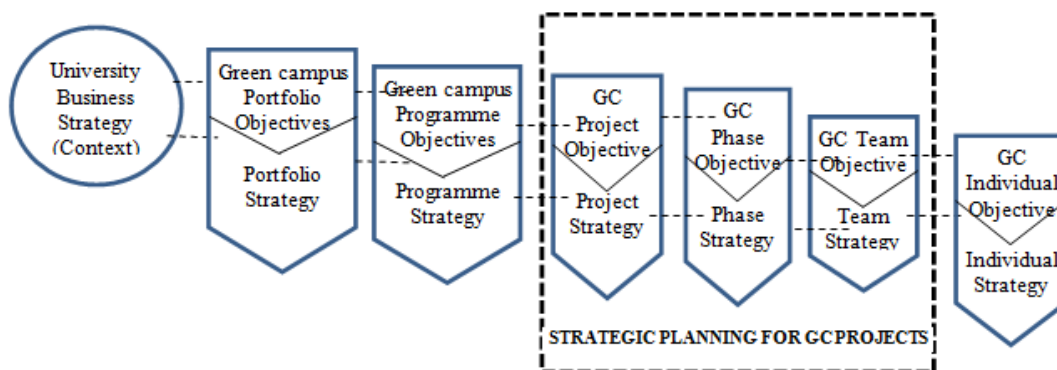


Figure 1: Linking university corporate and green campus project strategy (Source: Adapted from Morris and Jamieson 1997)

Green campus portfolios, programmes and projects

Adopting Turner and Simister's (2000) argument, the majority of green campus projects will take place as part of a portfolio of several green campus projects or programmes. A green campus project portfolio will be a set of projects which perform better if managed in a coordinated way (Platje, Seidel, and Wadman 1994; Artto, Martinsuo, and Aalto 2001). Using Cooke-Davies (2002, 2004) lenses on portfolio management, it could be strongly argued that "*choosing the right project*" will be mainly covered under green campus project portfolio management, while green campus project management will focus on "*doing the project right*".

Green campus programmes

Thiry (2004) argued that programme management is used to coordinate projects which have mutual aim and is the most suitable in evolving scenarios. Hence, both green campus portfolio management and programme management will thus focus on prioritizing resources and optimizing the outcomes and green campus programme management will remain focused on daily implementation management than green campus portfolio management, which will be more periodic in nature (Bartlett, 1998; Partington, 2004; Reiss, 1996). Furthermore, it will be possible within a university setting to implement strategy through green campus programme management and involve continuous re-formulation and adjustment.

It is important to note that green campus programmes will often be long-term and as a result may encounter uncertainty and ambiguity (Thiry 2004).

Green campus projects

Green campus projects, will have an individual and specific objective and follow a "*single development life cycle*." Application of Turner's (1999) work suggests clear and detailed defining of project (say recycling project), its plan and its alignment with project strategy.

Using Morris and Jamieson's (1997) findings in their case studies as a basis in predicting possible developments in green campus projects, it will be expected that universities will need project strategy which can manage the green campus project through its entire life cycle.

Required competencies, roles, responsibilities and accountability for moving strategy supporting green campus initiatives

According to Morris and Jamieson's (1997), it is not possible to translate university corporate strategy into green campus project strategy by process alone. Moving strategy through such processes and practices as discussed above will require an extensive range of personal competencies (for details on competencies refer Hornby and Thomas, 1989), and a clear definition of roles, responsibilities and accountabilities within the university and between academics and non-academic personnel. For lack of space and brevity, it is not possible to discuss in detail an appropriate competency framework and associated competencies, but core competencies related to project strategy provided elsewhere (in Morris and Jamieson 2004) are recommended.

PROJECT MANAGEMENT SET-UP AS A FRAMEWORK FOR MANAGING GREEN CAMPUS INITIATIVES

Universities as PBO by default need to become formal PBO if they want to manage green campus initiatives to sustainable ends. Graham and Englund (2004) provide a sound and simple implementation process as illustrated in Figure 2 with adjustments to suit the theme of this paper.

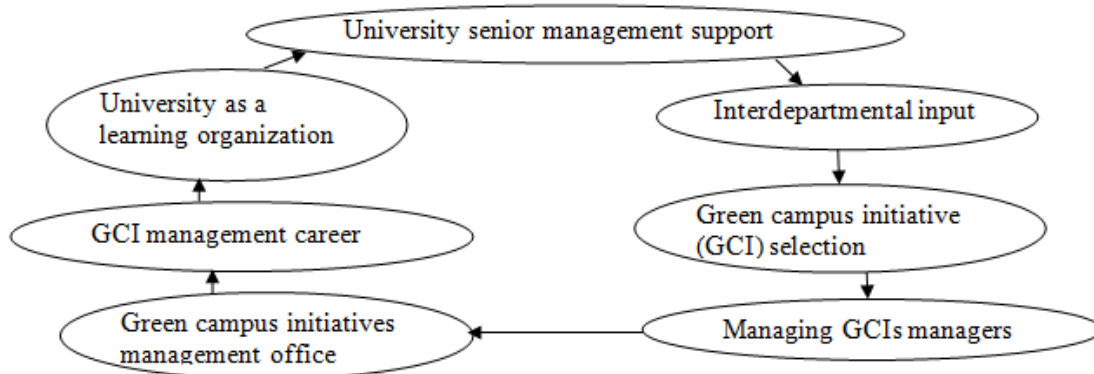


Figure 2: A Process for campus green initiatives (projects) success

Source: Modified from Graham and Englund (2004)

Graham and Englund (2004) in their seminal work argue that the implementation process begins with developing university senior management support. They further argue that if this is not accomplished, most of the succeeding steps will fail and the University will require new strategic leadership. Advancing it further, they emphasize the need to develop a green campus initiatives process using interdepartmental/school input. Without this input, they caution that the process will be unsuccessful because the department or college or school level cooperation is important. Developing a process for green campus initiative (GCI) (project) selection is recommended as the next step in the implementation process. They caution again that if this is not done correctly, there is a strong chance that massive fights for resources among competing projects could ensue. The fourth step is recommended to involve developing University upper managers' abilities in managing green campus initiative (GCI) managers. They further argue that if this is not done, there is a strong possibility of returning to the old ways of managing and not advancement to green campus initiative (GCI) management. Other subsequent steps recommended by Graham and Englund (op.cit) involve developing a campus initiative (GCI) management (project management) office which will help in (a) expediting the project management maturity scale, (b) determining a campus project management career ladder within the university non-academic staff cohort, (c) creating a learning organization to leverage strengths and (d) ensuring that past mistakes (sequence challenges) as discussed above are not repeated. The seven steps discussed briefly above are central to creating an environment for successful green campus initiative (GCI) management. For lack of space and brevity it is not possible to analyse each step in detail but details are found elsewhere (e.g. in Graham and Englund 2004; Turner and Simister (Eds) 2000).

As the 'green revolution' thinking pressures universities to embrace it fully in a sustainable way, university executives are obliged to adopt a new organizational mind set - to think about greening the campus differently. As opposed to 'business as usual' tack where green campus initiative (GCI) are ad-hoc and poorly funded, university top

management is required to target and achieve university goals in a new way. Rather than what Dinsmore (1999) refers to as “*silo thinking*,” university executives must perceive themselves as managers of a web of simultaneous green campus initiatives (GCIs) - green campus projects that include operational improvement and university turn-around programmes, as well as traditional capital expansion and information technology undertakings.

In the setting described above, the university executives perceiving themselves as managers of a web of simultaneous green campus initiatives (GCIs), and staff within departments/schools see their work as that of managing and successfully completing GCIs, as opposed to occupying a slot on a static university structure. At the coal face (at GCI) level projects will go through a university project management methodology which is designed around the university agreed project life cycle through phases: concept phase; planning phase; implementation phase; and ownership phase.

In order to have a sound internal university system, which is based on a particular project management methodology, GCIs will be organised into projects, programmes and portfolios. Hence a bottom-line focus for multiple GCIs under a common umbrella, with emphasis on the information consolidation and control side management.

The details on how GCIs will be accommodated through the life cycle and how a bottom-line focus for multiple GCIs will be managed are beyond the scope of this paper but could be found elsewhere (for example, Hartmann 1998; Turner 1999; Rwelamila 2007; Bolles 2002; Project Management Institute 2014).

CONCLUSIONS

It emerges from the review that the green campus initiatives are going to be part of modern day higher education institutions. Sustainable GCIs will require universities which are committed to embrace project management best practices through what is known as 'enterprise project management' as a formal culture. Creating this culture will require specific and well thought five steps suggested by Graham and Englund (2004). These will include:

Step I: the need for the university to adopt and adapt formally a PM discipline, methodologies and techniques, policies, processes, procedures, and tools.

Step II: the need to put necessary structures in place - supporting GCI management champions, formally title and train GCI managers and sponsors, form a GCI management council or steering committee, and involve functional management (both academic and non-academic) in GCI and programme reviews and implement a GCI that drives a concerted effort to pull everything together.

Step III: aim to simplify by dismantling activities, structures, reports and metrics that detract from rather than support progress. Select people who are enthusiastic and knowledgeable about GCIs so that GCIs core teams accelerate their progress from forming to performing.

Step IV: the need to expand capabilities through generating new knowledge and sharing new best practices that expand the realm of what is possible both within the university and with outside partners.

Step V: the need to implement a strategic green campus programme office as a linchpin for implementing and maintaining a project approach across the university. It is important to note that the strategic green campus programme office will add value

by ensuring that GCIs are performed within established procedures and are in line with university strategies, and completed in ways that add value.

Therefore, it can be concluded that there is a need to further explore application of project management philosophies in the area of green campus management at the higher education institutions.

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THE ROLE OF SUSTAINABILITY ASSESSMENT IN SUSTAINABILITY MANAGEMENT FOR URBAN REDEVELOPMENT

Daniel Gilmour¹, David Blackwood, Ruth Falconer, John Isaacs and Edward Simpson

School of Science, Engineering and Technology, Abertay University, Dundee, UK

Sustainability assessment has the potential to influence decision making and hence to improve the management of sustainability. This paper presents the development and reporting of benchmark sustainability indicators and discusses the challenges of embedding sustainability indicators into existing process for urban infrastructure development. It links sustainability indicators with a range of tools that were implemented within a Sustainability Enhancement and Monitoring Framework for the £1billion redevelopment of Dundee Waterfront. The sustainability monitoring framework followed the UK and Scottish Government thematic indicator approach and provided a set of Sustainability Benchmark Indicators for assessing and managing a public sector funded urban redevelopment. The process of indicator development was iterative and consisted of three main activities, literature, interviews and document analysis. Indicators were finalised through close working with Dundee City Council, Scottish Enterprise and partnership stakeholders. The indicators were successfully established in 2010 within Dundee City Council at project and departmental level, providing the link across policies, programmes and projects. The indicator development process is discussed and the findings of a January 2015 review of changes in the benchmark indicators will be reported. The transition of the indicators over time and its impact on future sustainability enhancement opportunities are evaluated alongside the implications for sustainability management of Dundee Waterfront. The efficacy of the benchmark indicators to support sustainability management over the planned 30 year programme of urban redevelopment is discussed. The wider implications of the findings of the Dundee Waterfront project are reviewed in the context of current work on sustainability assessment.

Keywords: sustainability assessment, decision making, knowledge management, sustainable development.

INTRODUCTION

Sustainable Development indicators are an important tool in the management of cities, enabling the benchmarking and measurement of progress over time (Siddall *et al.* 2013). Indicators can be used to direct urban decision making and support urban design decisions, assisting engineers make sense of inherently complex cities (Rogers 2012). Engineers and construction managers implement design, control and co-ordinate activities on site and ensure that management systems work effectively. This role increasingly also involves the management of sustainability, where sustainability assessment can be actively used to support the management of sustainability across the project life cycle (Thompson *et al.* 2011).

¹ d.gilmour@abertay.ac.uk

The Local Government in Scotland Act (2003) specifically requires that “*the local authority shall discharge its duties under this section in a way which contributes to the achievement of sustainable development.*” Within this context, the scale and regional importance of the £1billion Dundee Waterfront Development requires adherence to the principles of sustainable development and this must be demonstrated to Partnership bodies, private investors and the public as well as to the Scottish Government in a transparent way.

Abertay University provided support to Dundee City Council Engineers Department between 2007 and 2013 to identify opportunities to enhance the sustainability of Waterfront Infrastructure Provision. The approach was based on a theoretical Sustainability Assessment and Enhancement Framework (Blackwood *et al* 2014) which required a set of Sustainable Development Benchmark Indicators to be developed and embedded in the Waterfront Team’s process to, not only monitor, but also enhance sustainability. The sustainability indicators act as a benchmark for the project reflecting the goals and aspirations of the waterfront project as set out in the Dundee Waterfront Master plan. The Assessment and Enhancement framework is shown in Figure 1.

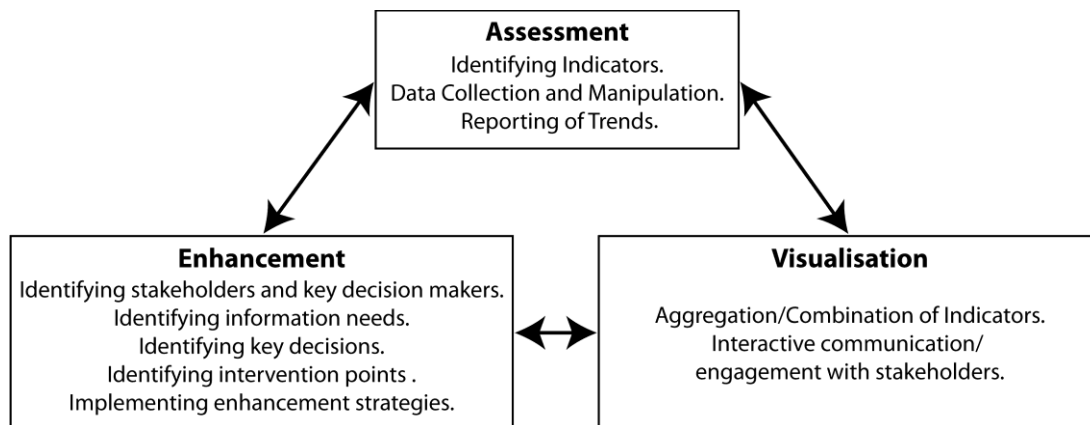


Figure 1: The SAVE Framework

This paper presents the findings of a review of the use of Sustainable Development Benchmark Indicators to enhance the sustainability of the Infrastructure Stage of Dundee Waterfront 2010 -2015. During the period of the study, significant stages of the Waterfront Development have been completed with the demolition and realignment of Tay Road Bridge ramps, demolition of roads and buildings, which previously separated the city centre from the waterfront. In their place, a new grid iron street pattern to make available 5.5 hectares of development area. The sustainability enhancement activities undertaken by Dundee City Council Waterfront Team during this period are summarised and their impact on the benchmark indicators evaluated. The review provides data for each of the indicators alongside an interpretation of the trends in the indicators over the period 2010-2015.

USE OF BENCHMARK INDICATORS

Indicators have been widely used by both policy makers and academics in sustainability assessment (Walton *et al.* 2005; Hak, 2007; UN 2007; Pultz and Ramstiner 2009) with well-chosen indicators considered as an effective technique for assessing sustainability (Reed *et al.* 2006). Indicators help to break down the sustainable development concept, to give it a clearer definition (Porta and Renne 2005), and hence, to make it more comprehensible. Simply put, an indicator is

something that helps us understand “*where we are, which way we are going and how far we are from where we want to be*” (Simon 2003, P2.). Indicators can provide crucial guidance for decision-making in a variety of ways. They can translate physical and social science knowledge into manageable units of information that can facilitate the decision-making process. They can help to measure and calibrate progress towards sustainable development goals. However, Dahl (2012) states that perhaps the most significant effect of an indicator, particularly during its early adoption, can simply be to make a problem visible therefore sensitising decision makers and the public to expand the basis for decision making. Development of indicators of sustainability can be seen as the first step towards the operationalisation of the concept of sustainability.

A sustainability monitoring framework was successfully established for Dundee Waterfront in 2010 (Gilmour *et al.* 2011). The process of indicator development was iterative and consisted of three main activities, literature, interviews and document analysis. Indicators were finalised through close working with Dundee City Council (DCC), Scottish Enterprise and partnership stakeholders. The appropriateness of the development process and currency of the indicators was confirmed through workshops with the Scottish Government and the Improvement Service. The system was designed to utilise Scottish Government Single Outcome Agreement (SOA) meta data to populate indicators in post baseline data compilation and reporting. This use of SOA data as part of the Sustainability Monitoring Framework is in keeping with the use of the SOA strategic Outcomes as the basis for operationalising the principles of sustainable development as illustrated in the DCC Sustainability Development Policy Statement.

The 2009 indicator report (Gilmour and Blackwood, 2009) set out the 6 indicators that were expected to be influenced by activity during the Waterfront Infrastructure Stage. These were:

- Tourism numbers (Economic);
- Tourism spend (Economic);
- Waste (Environmental);
- Air (Environmental);
- Noise (Environmental);
- Acceptability (Social).

The report also established that other indicators were not expected to change due to influence of the Waterfront until Plot Development or completion of the Dundee Waterfront programme. It is expected that the indicators will demonstrate the regional impact as set out in the 2001 Master Plan therefore changes observed in these indicators should be attributed to wider activities undertaken by Dundee City Council to progress towards SOA Outcomes to 2017. Table 1 presents a summary of the benchmark indicator trends across the 26 indicators Economic (10), Environmental (7) and Social (9) categories shows 15 indicators have moved in the desired direction across all the categories, with only 2 indicators moving against the desired direction.

Table 1: Summary of benchmark Indicators trends 2010 -2015

Economic		Environmental		Social	
Demographics		Green space/public space		Housing provision	
(City Wide)	✓	(Direct)	...	(Direct)	✓
Retention of skills base			Waste	Health & Well being	
(City Wide)	✓	(Direct)	✓	(City Wide)	✓
Knowledge based employment			Air	Community	
(City Wide)	×	(Direct)	✓	(City Wide)	×
Employment			Water	Social Inclusion	
(City Wide)	~	(Direct)	...	(City Wide)	✓
Capacity to stimulate investment			Noise	Participation and responsibility	
(Direct)	✓	(Direct)	~	(Direct)	✓
Tourism numbers			Energy	Active community participation	
(City Wide)	✓	(Direct)	...	(City Wide)	✓
Tourism			Travel	Acceptability	
(City Wide)	✓	(City Wide)	✓	(Direct)	...
Regeneration				Confidence	
(Direct)	~			(City Wide)	✓
Job creation				Amenity value	
(Direct)	✓			(City Wide)	...
Economic output					
(City Wide)	~				

Indicator moving in desired direction ✓ Indicator showing no significant change ~
 Indicator moving against desired direction × Not sufficient information ...

INFLUENCE OF SUSTAINABILITY ENHANCEMENT ACTIVITIES

There is a strong evidence of the use of sustainability assessment in promoting learning and informing decision making across the lifecycle of a project. Pope *et al.* (2004) identifies the evolving nature of assessment from purely technical to promoting stakeholder engagement, dialogue and learning. Sustainability assessment is increasingly being viewed as an important tool to aid decision making (Morrissey *et al* 2012). The role of sustainability assessment in sustainability management is identified by Thompson and El-Haram (2014). Kaatz *et al.* (2006) reflects on the opportunities to enhance the effectiveness of assessment practices in influencing construction decision making. Shaw *et al.* (2012) advocate that in order to achieve the best sustainability outcomes it is important to undertake assessment approach that considers all aspects holistically at all phases of construction process.

Sustainability assessment has the potential to influence decision making by providing information to support the decision process and hence result in actions during the design and construction activities that will positively influence the sustainability of the development. Part of the Assessment and Enhancement framework involved the detailed knowledge elicitation and process mapping methodology to identify and classify knowledge and identify Knowledge Disclosure Points has been reported previously in Gilmour *et al.* (2013). These Knowledge Disclosure Points identified where, when and how sustainability could be influenced. Abertay University supported DCC City Engineers Division staff to identify, devise and implement enhancement activities at these points in the process between 2007 and 2013. These were identified based on phase of infrastructure occurring, where activities were developed to positively influence the six infrastructure development phase indicators that were identified above. The activities are shown in figure 2 and described below.

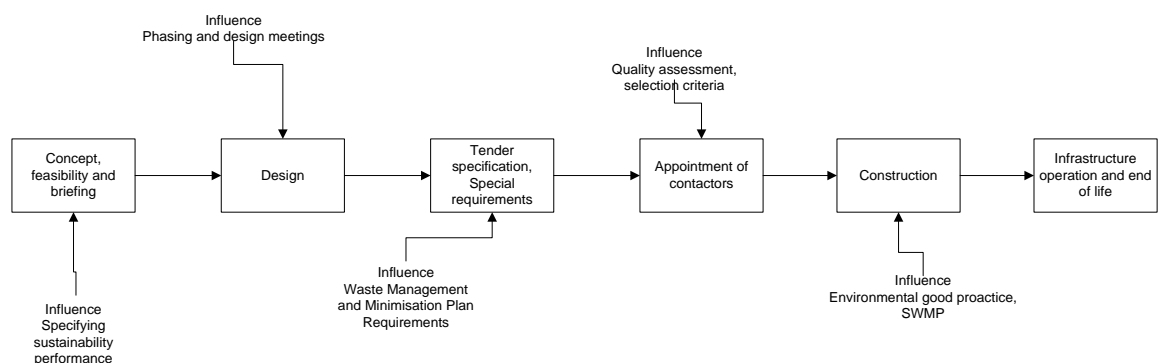


Figure 2: Enhancement Activities

Influence Phasing and Design meetings -This activity involved the creation of a Sustainable Development Issues Register by identifying sustainable development issues arising during the design and phasing meetings which required further consideration. From January 2007 the researcher contributed to over twenty relevant phasing and design meetings with the consultants White Young Green, Fairhurst and Dundee City Council project team. During these meeting the issues driving the design in relation to sustainable development were identified. These were then either raised and dealt with during the meeting if appropriate, or identified in the sustainable issues register to be fed back to design team.

Waste Minimisation and Management Plan -Waste management support was provided through the period of the commission to identify opportunities to recycle materials in the construction process. The aim of this activity was to link an understanding of the phasing of the project and the identification of opportunities for the specification of recycled materials during the design stage and to ensure best practice in recycling of materials. Assistance included developing a strategy to identify quantities and types of waste arising from the tunnel strengthening programme, identifying the management options with reference to the waste hierarchy and monitoring the waste arising and maximise recycling to inform future waste management approaches

Tender document preparation -Sustainability opportunities at tender preparation stage were reviewed for Contract 1 and Waste Management and Minimisation (WMM) was considered the most appropriate sustainability enhancement mechanism. The enhancement framework supported the development of tender documentation, particularly waste management policy wording and client expectations of contractors

approach to environmental best practice. Questions for the quality assessment and interview process were also developed along with a SWMP template based on DTI guidance to be included in the tender documents. In Contract 2 there was an opportunity to increase the emphasis of sustainability through WMM and increase the weighting on environmental performance during the quality assessment scoring. Detailed work was undertaken on developing a more robust quality assessment scoring for SWMP template included in the tender documents.

INTERPRETATION

Of the 26 indicators across Economic, Environmental and Social categories 15 indicators have moved in the desired direction, with only 2 indicators moving in the wrong direction. At the infrastructure stage, the activities were specifically designed to influence 6 of the indicators during Design and phasing and construction of the Waterfront Infrastructure. Table 2 presents these indicators alongside a narrative about the indicator trend and enhancement activities undertaken by the project team related to the indicator.

Table 2: Indicators influence by infrastructure stage enhancement activities

Indicator	Trend	Narrative	Enhancement activity
1f Tourism numbers 1g Tourism Income (City Wide)	✓ ✓	Tourism numbers were expected to be effected through all stages of the waterfront development. This was due to the vicinity to works relating to Discovery Point and Dundee Science Centre. It is positive to report that visitor numbers and tourism spend have not been detrimentally effected by construction period, and in fact both indicators have increased over the period. A contributing factor may be the close working between the waterfront team and tourism locations.	Sustainability Issues Register identified issues during design and phasing of infrastructure in particular traffic routing and disruption to services and ensure the sustainability and Waterfront objectives were maintained in the design.
2b Waste (Direct)	✓	100 % of Dundee Waterfront project contracts have employed Site waste management plans to ensure that waste is re used/ recycled where possible. The amount being reused or recycled is over 96 % across the project exceeding best practice.	Design and Construction Checklist, Waste management, WRAP & SWMP in contract documentation. The register and checklist identified issues during design and phasing of infrastructure, identify opportunities to recycle material in construction Waste management approach to specify during the design stage, ensure best practice to maximise the use of recycled materials in design and embedded in contract documentation.

2c Air (Direct)	✓	With significant traffic management required during the waterfront project, this indicator was put into the monitoring framework indicators to help assess any changes in traffic flow based on Seagate air monitoring station. From these readings a positive trend is occurring.	Sustainability Issues Register - The register identified issues during design and phasing of infrastructure traffic routing and traffic management
2e Noise (Direct)	~	Management of noise and communications to identified noise sensitive receptors (NSR) for the proposed work to be conducted out of normal working hours / or may be particularly disruptive has been successful in keeping complaints to minimum.	Sustainability Issues Register - The register identified issues during design and phasing of infrastructure traffic routing and traffic management, noise level, timing, duration and location of activities.
3e Acceptability (Direct)	...	No additional survey has been undertaken to update the original acceptability of the Waterfront Master plan	The register will identify issues during infrastructure design and phasing as opportunities to engage with stakeholders in the decision process and ensure the sustainability and Waterfront objectives are maintained in the design. Acceptability of public was a main driver in design and phasing considerations, traffic management and night working.

The overall trend data shows 4 out of 6 indicators moving in the desired direction (with 1 with no significant change). This suggests that the implementation of the sustainability enhancement approach by the Waterfront Team to positively influence these indicators has been successful. The indicators are now also used in Dundee City Council at project and departmental level, providing the link across policies, programmes and projects. The process of indicator development was iterative and undertaken over a three year period working closely with the project team and wider stakeholders. However, institutional and governance challenges still remain around identifying those who will be responsible for the continued publication of the indicators and how the data and reporting will be sustained and funded over time during the Plot Development and subsequent stages of the Waterfront Development. The indicators set was closely aligned to existing data collection for the Scottish Government Framework and Single Outcome Agreement which provided a data collection mechanism that would continue in the foreseeable future. If this had not existed the Council would have had to commission an external party to collect the data making it less certain that the indicators would have been successfully accepted within Council. This is exemplified by the absence of data for indicator 3e Acceptability because no additional survey was undertaken to update the original assessment of

acceptability of the Waterfront Master plan since this was out with the Council's Single Outcome Agreement data collection strategy.

DISCUSSION

The three interconnected concepts of sustainability assessment, decision making and knowledge management have been explored through the waterfront case study. The investigation has developed knowledge elicitation and mapping techniques (Gilmour *et al.* 2013) to improve sustainability assessment practice and, in turn, provided closer integration of assessment and decision making. The findings of the work add to current knowledge, in relation to the potential for knowledge management and benchmark indicators, to demonstrate current practice, to improve decision making and support sustainability enhancement.

The use of indicators in the case study supports the case presented in literature for the potential for sustainable assessment to support sustainability management. The wider implications of the findings of indicator development can be related to the current work on sustainability assessment and management as seen in Thompson and El-Haram (2014). In addition, Eames *et al.* (2013) identifies a critical challenge is to develop the knowledge capacity within public organisations for sustainable transitions. Indicators are considered to be effective tools in monitoring communicating sustainability therefore making the concept of sustainability operational. These views are also supported by other authors such as Mascarenhas *et al.* (2010). The literature focuses on the value of information and knowledge for monitoring and communication of sustainability issues but it does not explore how that information and knowledge can be applied to positively influence sustainability in projects. Table 2 suggests that the initiation of planned enhancement activities at key stages in the process (as defined by Knowledge Disclosure Points) has positively influenced sustainability and has demonstrated the potential benefits of an integrated Sustainability Assessment Monitoring and Enhancement Framework.

CONCLUSIONS

A sustainability monitoring framework, incorporating a set of indicators was successfully developed for Dundee Waterfront in line with the assessment component of the theoretical framework. Enhancement activities were successfully identified and implemented by the researchers and the DCC City Engineers staff to positively influence direction of change of selected indicators and hence to enhance the overall sustainability of the Development. There is evidence that the enhancement activities have been successful. This improvement of sustainability practice within the Dundee Waterfront Project supports the case for a wider application and testing of the Sustainability Assessment and Enhancement Framework.

The findings from this study support literature which consistently proposes that the use of indicators can increase transparency and accountability, thereby increasing the availability of information to engage stakeholders and support decision making. It has also supported the use of knowledge mapping to influence sustainability through identifying where, when and how sustainability can be influenced. The case study has however identified a challenge to continued viability of the Framework on long term projects (25years plus), that of ensuring high level support of the concept to ensure its continued application by temporally transient groups of stakeholders. It has also highlighted an expected indicator interpretation issue related to the use of Single Outcome Agreement data for a number of indicators and the challenge of attributing

the influence of enhancement activities on the Waterfront with wider activities undertaken by Dundee Partnership to progress towards SOA Outcomes to 2017.

Overall, it can be concluded that developing theme orientated indicators based on policy and practice is an effective mechanism to improve sustainability practices. The use of sustainability indicators provides the benchmark to measure progress, combined with enhancement activities and presents an approach which can be used by other organisations.

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GENERATING SOCIAL VALUE THROUGH PUBLIC SECTOR CONSTRUCTION PROCUREMENT: A STUDY OF LOCAL AUTHORITIES AND SMES

Christopher Burke¹ and Andrew King

School of Architecture, Design and the Built Environment, Nottingham Trent University, NG1 4BU, UK

Difficult economic conditions exert additional pressure on government organisations to achieve more with less. The UK Government has redefined value for money, calling for Public Sector Organisations (PSOs) to practice the principles of sustainable procurement; whereby economic, environmental and social considerations form the selection criteria on tenders for public sector contracts. Support for this new approach has been reinforced by placing a duty of Best Value on Public Procurement Officers (PPOs) and more recently, the introduction of the Public Services (Social Value) Act 2012 (the Act). The research adopts a Grounded Theory (GT) approach, with nine unstructured and semi-structured interviews conducted with four local authorities, three construction Small and Medium Enterprises (SMEs) and two social value practitioners. The findings suggest there is a lack of adoption among procurers of public sector construction contracts, with up to 75% of local authorities not including reference to the Act or social value in their corporate procurement strategies. The SMEs involved in this study are at varied stages of development, with one organisation arguably demonstrating a sophisticated approach to social value. Importantly, the findings suggest that there is a lack of guidance and lack of prominence given to social value in tenders. This paper advances current knowledge in the field by providing a foundation for further research in a new area of study.

Keywords: social value, public procurement, SME.

INTRODUCTION

The introduction of the Public Services (Social Value) Act 2012 (the Act) can change the way that Public Sector Organisations (PSOs) procure services, goods and works; with PSOs now required to consider economic, social and environmental wellbeing in connection with public sector contracts to achieve maximum value for money. This means that PSOs will be assessing bids beyond the lowest price to evaluate quality aspects when awarding contracts.

Obtaining value for money is the overriding factor that determines public procurement decisions. In recent years, questions over what constitutes value for money has stemmed from the economic downturn which placed unprecedented pressure on Public Procurement Officers (PPOs) and businesses, with stakeholders demanding increased transparency and accountability. Furthermore, leading economists, political figures and social scientists around the world have called for national progress measures which go beyond Gross Domestic Product (GDP); encompassing economic, social and environmental progress (Stiglitz *et al.*, 2013). This has struck a chord in the

¹ christopher.burke2011@my.ntu.ac.uk

United Kingdom (UK), with the current government introducing National Wellbeing Measures and promoting the ideological theme of ‘the Big Society’ in the 2010 general election. There are two fundamental strands to the Big Society: a commitment to the free market, and the empowerment of communities. Furthermore, the notion of placing more power in communities led to the introduction of the Localism Act 2011, and subsequently; Local Enterprise Partnerships (LEPs), neighbourhood planning and devolving power from central government to local government authorities.

From a business perspective, stakeholder pressures can be attributed to current trends surrounding sustainability and Corporate Social Responsibility (CSR). Porter and Kramer (2011) suggest that businesses should be working towards Creating Shared Value (CSV), a new conception of capitalism where business is placed at the centre of meeting societies challenges. Milton Friedman famously criticised the idea that businesses should partake in solving society's wider issues, arguing that profit maximisation contributes to decreasing unemployment, and increasing wages, purchases, investments and taxes (Friedman, 1970). In contrast, Porter and Kramer (2011) believe that this approach, which has dominated management thinking throughout the 20th century, does little for communities which do not benefit from the profits a company creates from operating in that area. CSV has received widespread criticism from CSR professionals who argue that it just gives a current trend a new name (Junge, 2011). However, the significant contribution of CSV is that it has been the catalyst for a debate on the role of business in the 21st century, a debate which should not be excluded from businesses operating in the construction industry (Awale and Rowlinson, 2014).

Myers (2013) highlights that the construction industry is often identified as the first sector to require specific attention in addressing the three pillars of the sustainable agenda. The socio-economic impact of the construction industry is significant, as economic growth results in increased societal demands, including essential infrastructure such as housing, roads, bridges, water, electricity and telecommunications. The construction industry is also a major source of employment, accounting for 2.93 million jobs, equivalent to 10% of total UK employment (BIS, 2013). Therefore, it is clear that the construction industry can contribute to the UK Government's wider goals of sustainable development. However, sustainable development is often misinterpreted with environmental dimensions of sustainability, thereby overshadowing the social facets. That said, it is difficult to talk about one strand of sustainable development without considering its implications on the other two strands of the triple bottom line construct, with Brennan and Cotgrave (2014) likening it to a three legged stool.

Corporate Social Responsibility

Jones *et al.* (2006) carried out a study seeking to explore CSR strategies among 37 of the UK's leading construction companies, concluding that many of their CSR policies appear aspirational and lack verifiability. The majority of studies on CSR theory focus on large or multinational organisations, with conventional approaches to CSR predominately having been developed around them. Arguably, there should be a greater focus on Small and Medium Enterprises (SMEs) in construction; with SMEs accounting for a 72.4% of total UK construction turnover and constituting approximately 99% of firms (BIS, 2014). Moreover, there is a high degree of fragmentation in construction with responsibility and performance cascading down the supply chain (Brennan and Cotgrave, 2013). This is evidenced in an analysis carried

out by EC Harris, which has shown that on a typical £20-25million project, the main contractor will manage approximately 70 subcontracts (BIS, 2014).

Social Value

Similar to the variety of definitions of ‘sustainability’, there is a lack of clarity in defining social value. In the context of the Act, social value can be broadly defined as:

‘The additional benefit to the community from a commissioning/procurement process over and above the direct purchasing of goods, services or outcomes.’ (NHS North West Commissioning Project, 2010)

The concept of social value is purposefully non-prescriptive within the Act, only requiring a ‘duty to consider’ the economic, environmental and social benefits which can be achieved through public procurement. A powerful element to the Act is that it applies at pre-procurement, asking PPOs to consider whether consultation with project stakeholders is required. Importantly, this includes consulting communities which have an interest in the finished building or scheme. As such, the Act takes account of the subjective nature of social value, driving PSOs to engage with communities to explore what they value. This is made more difficult by shifting priorities over time and between different members of the community (Fitton *et al.*, 2014).

Arguably, greater social value is created where PSOs take a more integrative approach to understanding the needs of the community, by taking account of the local nature of SMEs and their involvement in the communities they serve. This provides construction organisations with a dual role, whereby they can offer their own thoughts and ideas, possibly through early consultation with communities; thus gaining a competitive advantage when bidding for public sector contracts. In addition, scant literature exists surrounding the potential of participatory design processes which empower communities to alter their physical environment, taking considerations of social value beyond the construction process itself. Fitton and Guthrie (2014) support development in this area, stating that the social and environmental impacts of flood alleviation schemes should be just as important as the technical, commercial or operational considerations of the design. Successfully adopting this approach requires the construction industry to overcome the tendency to choose the option which offers lowest capital cost. However, the subjectivity of social and environmental outcomes makes it hard to evaluate the cost versus benefits in this scenario, something which may change as tools and methodologies for measuring social value are developed.

Measuring Social Value

There is no standard ‘one size fits all’ method to measuring social impact (Wood and Leighton, 2010; Mulgan, 2011; Severn, 2014). Social Return on Investment (SROI) has become the favoured tool for the UK Government, due to its ability to quantify and communicate social value with monetary outcomes (Wood and Leighton, 2010). The immediate attraction here is the belief that SROI offers a transparent and accountable monetary value which can be used to compare the ‘worth’ of tenders.

Work by Daniel Fujiwara at SImetrica has led to the development of the Housing Associations Charitable Trust (HACT) Wellbeing Valuation assessment tool, which includes the largest set of methodologically consistent social value metrics produced to date (The SROI Network, 2015). HACT’s innovative tool aims to address the challenges of placing a monetary value on non-market qualities such as ‘confidence levels’ and ‘sense of belonging to the neighbourhood’ by using large data sets from national surveys.

Another tool limited to measuring local impact has been produced by the New Economics Foundation, called Local Multiplier 3 (LM3), which can be used to calculate the economic contribution of an organisation to a specific outcome. Essentially, LM3 measures three rounds of spend within the defined 'local' boundary. Organisations carrying out an LM3 need to first collate data from their income source (round one), calculate outgoings on employees and supply chain (round two), and record how round two distributes their spend (round three). The many diverse tools available results in fragmentation and confusion, therefore limiting their use and impact within the construction industry to date.

Pointing to emerging practices in Europe, a number of contractors in the Netherlands have recently implemented a Social Return Performance Ladder (referred to as PSOBouw), which has been developed exclusively for the construction industry. With participating companies including multinational contractors VolkerWessels, BAM and Heijmans, PSOBouw broadly aims to measure the social return of increasing employment for those who find it difficult to access the labour market.

METHODOLOGY

A Grounded Theory (GT) methodology was adopted for this research to enable exploration of an under-researched area. GT was first introduced in the seminal text *The Discovery of Grounded Theory* (Glaser and Strauss, 1967) and allows the theory to emerge from the data. The work utilised theoretical sampling - interview participants were selected based on the developing theory.

Nine in-depth unstructured and semi-structured interviews were conducted with four local authorities, three construction SMEs and two social value practitioners over a four-month period in late 2014 and early 2015. The sample was broadly spread throughout England, with the exception of the three SME participants who were all based in the Midlands. The local authorities were all at an intermediate or advanced stage of embedding social value into their procurement decision-making processes. The three SME participants were all aware of social value through tendering for and delivering public sector work.

Unstructured interviews proved particularly useful in the early stages of the work, allowing the interview participants to lead the 'conversations with a purpose' (Burgess, 1984). Memos were used to lead the analytic work and fed into the evolving interview guides representing a move to a more semi-structured format. Similarly, the emergent nature of the open-ended semi-structured interviews allowed the interviewer to guide the interview with fluidity, thus allowing new areas of discussion to develop. Early topics of enquiry included the following:

- Understanding and awareness of social value;
- Perceptions of public procurement and barriers to procuring social value; and,
- Knowledge and perception of measurement tools (e.g. SROI and LM3).

Trustworthiness, credibility and transferability of the research drove the use of the GT layers of open, axial and selective coding based on fully transcribed interviews and detailed analytic memos. The thematic analysis of the textual data led to the construction of three central themes to be discussed in the results (see Figure 1).

To explore the awareness and adoption of social value across all local authorities in England, a search of published website data was carried out during the period 10th

February to 27th March 2015. The authorities' websites were searched for the following documents:

- The local authorities' latest publicly available corporate procurement strategy;
- A published social value policy; and
- A published social value toolkit.

The results from the documentary analysis were then quantified and used to supplement the data gathered in the interviews.

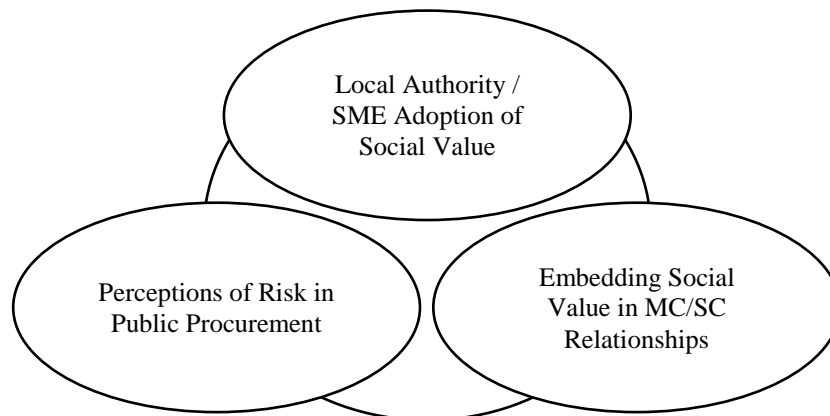


Figure 1: Central themes

RESULTS

Adoption of Social Value

The sample includes all 351 local authorities in England, with data collected in relation to whether the local authority: explicitly mentions social value and the Act within their latest available corporate procurement strategy; has a specific social value policy in place; or, has produced a social value toolkit. Social value policies reviewed typically summarised what social value means to the local authority, states their social value outcomes and outlines the scope of their overall approach. A social value toolkit covers these issues in significantly more detail, while also providing guidance for PPOs on precisely how they can procure social value outcomes.

The purpose of this pilot-study was to measure the adoption of social value among local authorities at a strategic level, with a binary yes or no methodology applied for simplicity in reporting the findings. It is important to recognise several limitations to the adopted approach. First, the data collection relies on local authorities' website data being up to date, which is often not the case within the small district authorities. Second, the simple yes or no categorisation is reliant on the author's interpretation where the indicated approach was ambiguous. Third, the sample only includes local authorities in England, thereby excluding 22 in Wales (the Act only applies in England and Wales). Furthermore, the selected sample does not consider any of the other PSOs which have to comply with European Union (EU) procurement rules.

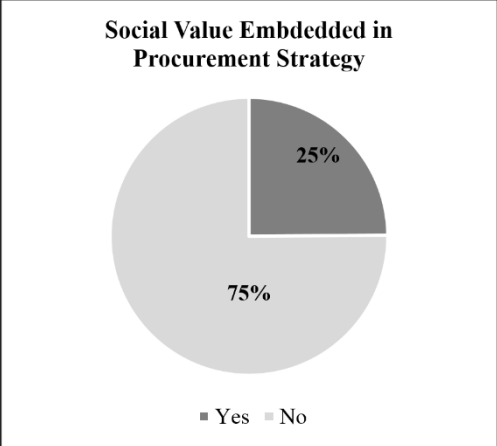


Figure 2: Local authorities with social value embedded in their procurement strategies.

The results indicate that 25% of local authorities have embedded social value in their corporate procurement strategies. Although this is not necessarily a fully accurate representation of adoption by local authorities and PPOs, the low percentage of local authorities implementing the Act at a strategic level echoes literature suggesting that many local authorities are yet to see the potential of embedding social value in procurement decisions (Cabinet Office, 2014). With up to 75% of local authorities not embedding social value in procurement strategies, and less than 10% having a specific social value policy or toolkit; this raises concerns that social value is not seriously considered in commissioning and procurement decision making across England.

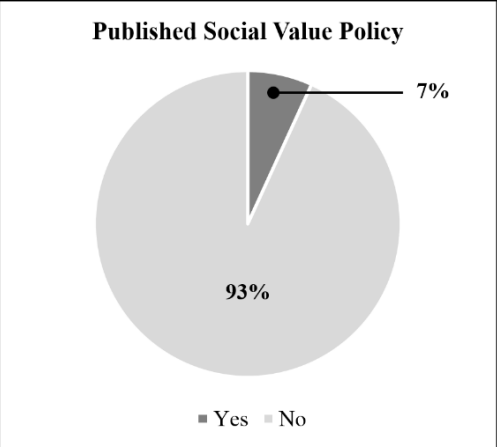


Figure 3: Local authorities with a published social value policy.

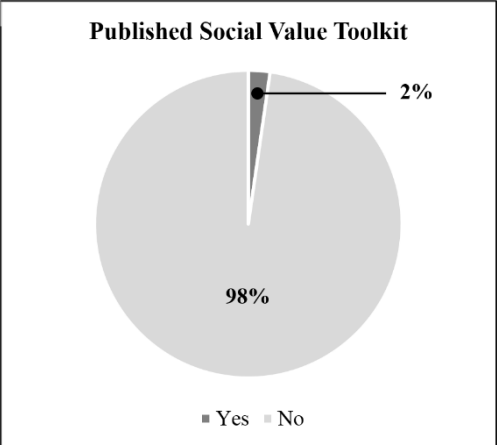


Figure 4: Local authorities with a published social value toolkit.

The four local authorities interviewed had sought to place social value at the centre of their procurement strategies, with some having taken this further with either a social value policy or toolkit. One participant, the Head of Procurement at a local authority, viewed their toolkit as important in raising awareness among SMEs, commenting:

“[...] a lot don't understand it [...] I think there is probably quite a big challenge, to try and educate and support providers [...] to get a better understanding of what we mean by the delivery of social, economic and community benefits.”

A social value policy or toolkit can operate as a tool for providers to understand what their client wants to see in tender submissions by highlighting their strategic objectives. Although some local authorities, including those interviewed, are displaying good practice in this area, there is clearly still much variation in the way local authorities are applying these tools. This inconsistent practice can limit the success of SMEs when tendering for public sector contracts as they do not always have the time and resources to carry out extensive research for every project (Cabinet Office, 2015).

Moving to consider adoption by SMEs, awareness of social value and the Act is generally described as low (Battle, 2014). However, the three SMEs interviewed in this study point to the increasing importance of social value, with two of the three organisations currently in the early stages of adopting social value in their business activities. Drivers for adopting social value in their business practices included increasing their competitive advantage, improving the communities they operated within and to comply with clients' award criteria. For one participant, the Director of a roofing contractor, using social value to gain competitive advantage was a natural extension to their vision of operating a socially responsible business. This included increasing local expenditure through local employment and community involvement. The third organisation can be considered an exemplar model for adoption, displaying an advanced level of understanding in the social value they create. For example, this particular organisation is starting to engage with more sophisticated methods of measuring social value including the HACT Wellbeing Valuation tool and detailed approaches to SROI; having already evidenced their local impact using the LM3 assessment.

The SME participants have seen an increase in socially related questions in Pre-Qualification Questionnaires (PQQ) and Invitation to Tender (ITT) documents in recent years. The difficulties they experienced were mostly in relation to their ability to effectively communicate their plans to create social value when asked open-ended questions in tender documents. The respondents stated that there was often little guidance offered by PPOs, in addition to a sense that there was a ‘throw everything in’ ad-hoc approach to articulating social value outcomes. Moreover, it was clear this repeatedly led to an array of possible social outcomes, which arguably fail to respond to community needs.

It is unsurprising that SMEs are at different levels in understanding social value. In part, this is due to a lack of transparency in the evaluation of social outcomes and a corresponding deficiency in contract monitoring. As a result, many local authorities and providers are not learning from their social value-based activities. Crucially, this means that whilst some SMEs are developing innovative ways of creating social value, they may never be reviewed or appropriately rewarded.

Perceptions of Risk in Public Procurement

Despite legal backing from EU legislation (2014/24/EC), European case law and the recently revised Public Regulations 2015, the fear of legal challenges may explain the lack of adoption when procuring social benefits, as one local authority makes clear:

“[...] if you push the boundaries and try and deliver social value, but then you are perceived by unsuccessful bidders to give some suppliers an unfair advantage in doing so, then the risk of challenge exists [...]”

This view aligns with previous studies that there is a fear of challenge resulting from the perceived lack of clarity on what is legally permissible (see Cabinet Office, 2015; Richardson, 2015). However, this threat appears minimal in light of the recent EU and domestic legislative changes which explicitly support procuring social and environmental benefits in contracts (Cook *et al.*, 2014). The ‘link to the subject matter’ precedent has emerged as the major legal principle for sustainability considerations in public procurement, as held in *Concordia Bus Finland Oy AB v. Helsingin Kaupunki* [2003]. Conclusively, award criteria need not be purely economic in nature, providing; it is linked to the subject matter of the contract, does not confer an unrestricted freedom of choice on the procuring authority, it is expressly mentioned in the contract documents or tender notice, it is not indirectly or directly discriminatory, and complies with the principles of community law.

Embedding Social Value in Main Contractor / Subcontractor Relationships

The majority of main contractors have their own specific approaches to CSR and advertise the importance they give to operating a socially responsible business. However, the fragmented nature of the construction industry means that SMEs are often required to support their larger partners in meeting social requirements in contracts. This position was clarified by one local authority participant:

“A lot of the larger contractors that we would be working with, they will pass it down through their supply chain [...] and it will be their contractors or subcontractors, they actually deliver on it.”

SMEs tend to be enmeshed within communities and stand in a great position to deliver social value through the supply chain. However, there is a danger that SMEs are asked to deliver social outcomes on behalf of main contractors without a support framework which allows them to do so, as described by the following SME participant:

“[...] they always ask us how many apprentices we’ve got and if we can take an apprentice on. But then I’ll say ‘yes, but give us an apprentice in roofing’, and they’ll say they can’t.”

Although main contractors may have ambitious targets for social value articulated in tenders, the challenge can be turning the promises into reality. Whilst there are examples of main contractors having effective processes in place to ensure that social outcomes are delivered, many are still at the embryonic stage with an unplanned and ad-hoc approach which compromises performance on social value requirements.

CONCLUSIONS

Whilst the Act has attracted widespread support and interest from both the public and private sector it is clearly still in the early stages of development. Adoption to date at a strategic level by local authorities has been inconsistent across the country as evidenced in the study. This is the first attempt to measure adoption of the Act across all local authorities in England, with previous surveys relying on a self-selecting

sample (Cabinet Office, 2015), or across a range of PSOs (Social Enterprise UK, 2014). On the basis of the publicly available information on local authorities' websites, the findings suggest that up to 75% have not included a reference to the Act or social value in their corporate procurement strategies. Future planned work includes a more detailed study of adoption by local authorities.

SMEs, who are often the organisations left to actually deliver social value outcomes, tend to be unaware of the Act and have little visibility of the wider social value picture they are helping to create. Moreover, progress is slow as the social value created is often not reviewed as part of contract monitoring and feedback. Those organisations pushing this agenda are beginning to benefit to a limited extent through competitive advantage over other less developed organisations, but progress is slow and often disproportionate to the time, cost and resource expended. The importance of SMEs in developing social value is clear as they are often rooted in the communities in which they operate, thus have a greater understanding of community needs and ability to multiply local expenditure.

The findings presented within this paper are intended to provide a foundation for further research in an area where scant literature exists. This study only uses a small sample and provides a snapshot of the attitudes towards social value across a varied range of local authorities, construction SMEs and wider practitioners. Extending the sample population to include large construction contractors, housing associations and wider stakeholders such as community members is required. Additionally, future research should explore how social value is communicated through the supply chain with a case study into individual local authorities' construction projects.

Further research into the whole-life potential of social value is needed to assist in maximising value for money. To mature, the construction industry needs to advance from traditional commercial and technical notions of value, to consider the impact of the built environment on physical and mental health, how the physical environment can improve social relationships, reduce crime, and improve overall wellbeing. Moreover, the design and construction process should be reconfigured to incorporate collaborative processes such as Inclusive Design and Participatory Design.

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SITTING BETWEEN TWO CHAIRS: INTRODUCING SOCIAL SUSTAINABILITY IN THREE LARGE SWEDISH CONTRACTOR COMPANIES

Christian Koch¹ and Martine Buser

Department of Construction Management, Chalmers University of Technology, Gothenburg, Sweden

Recently the largest Swedish contractors have advertised social sustainability as a new competence in their social housing portfolios. They have created organisational functions related to the concept and integrated it in their strategies. Their presentation includes terms such as: attractive, safe and fair areas; social responsibility; consultation and involvement of the residents; as well as new forms of partnership and financing. In doing so, these companies have stepped aside of their traditional contractors roles as providers of technical and environmental friendly new build and renovation. This development of the contractors' business towards societal issues brings new challenges. Based on one in-depth case study juxtaposed with two other cases we analyse how the in-depth case company has tried to introduce social sustainability in its organisation and why it has failed to do so. We show that the two others are far thinner in their claim of social sustainability. The case studies include interviews, workshops, grey publication and advertising material. We draw on the theoretical concepts of hybrid organisation, project based organisation, marketing and sustainable leadership approaches, in particular the concept of "*ambivalent supplication*" defined by Parkin as the moment when a company is willing to engage in a sustainable process but at the same time not quite ready to leave business as usual. The results underline the following issues: the competing strategic priorities, the complexity of implementing strategy across various business functions, the lack of recognition from the financial markets and the differing definitions of sustainability across cultures.

Keywords: contractors, social sustainability, Sweden.

INTRODUCTION

Sustainable development and climate mitigations have become increasingly influential (Ghahramanpouri *et al* 2013). While the term was first employed in relation to environment, it no longer considers sustainability solely as an environmental concern but incorporates economic and social dimensions as well (Axelsson *et al* 2013, Opoku and Ahmed 2012). However, if a social dimension to sustainability is commonly accepted, there are competing definitions of what it means (Boström 2012). In addition the practical applications of social sustainability are not anymore directed only by public regulation, their developments link to changing social needs of individuals and communities add complexity to the process of achieving these goals. Building companies including contractors do to some degree take on board these social sustainability goals, but they tend to replicate the methods used previously in urban development (Öresjö 2012). It is more than likely that they will achieve the

¹ christian.koch@chalmers.se

same limited results. Therefore there is need for leadership and appropriate innovative approaches to contemporary challenges in social sustainability. At the same time however, the current harsh economic conditions, means that many building companies are struggling for staying competitive. Therefore relevance of the corporate engagement in sustainability practices becomes contested. Increasing problematisation of adopting a proactive role in balancing economic, social, and environmental sustainability development occurs, and the companies' commitment appears unstable and contingent.

The purpose of the paper is to first develop a framework for understanding contractor's implementation of social sustainability in their service product and then analyse the case of a Swedish contractor who has tried to implement a concept of social sustainability in social housing projects.

Built on a literature review a framework for understanding implementation of social sustainability in contractors' services is developed. It picks three important elements of the extensive but imprecise task of delivering social sustainability: to develop a business concept, embed it in the project based organisation and create reference projects. The qualitative empirical work focuses first on one of three building contracting companies involved in renovation programmes in socially deprived areas in Sweden. Second this first in depth case is compared to two other. The contribution is empirical findings and analysis of implementing social sustainability in construction businesses.

The structure of the paper is the following. First a method section, then a framework of understanding, then the in-depth case, then a discussion including also the two other cases and a conclusion.

METHOD

The method is multidisciplinary with interpretive sociology as a core (Burrell and Morgan 1979, Bryman and Bell 2011). The frame of understanding is based on a selective literature review drawing on management and organisational theories, transition theories and sustainability theories.

The contracting companies have been selected for their high public profile in both professional and general media on the issue on renovation of the deprived neighbourhood in Sweden. They are thus spearheading companies and understood as deviant from the rest (Flyvbjerg 2006). They are all three among the ten largest contractors in Sweden with more than 10.000 employees.

The first company (Contractor 1) has an apparently rigorous and implemented social sustainability concept. This contractor has four main business areas and units and operates broadly in Sweden and abroad. The case study builds on interviews, workshops, grey publication and advertising material. Two master theses are central sources Bergendahl and Käll (2014) and Starke (2013): The first including 7 interviews, 6 with managers involved in the social sustainability effort and one with a customer of the social sustainability concept; the second four interviews with the same contractor's managers. For the two other companies web search for material, article search on a Swedish database for news media and collection of previous elaborated material was carried out. The case analysis appreciates each case as unique but allow for qualitative comparison (Stake 2000).

Contractor 2 operates has also an international profile. The corporate organisation is complex and involves a large number of financial, legal and business units. Contractor

3 operates a large number of business areas, and is organised in several legal units in Sweden and abroad.

Some references have been left out as they would compromise the anonymity of the case companies, similarly too precise dates have been avoided to assure anonymity. It is a limitation that Sweden as a context is particular for working with social sustainability. The qualitative method covers three companies and a few projects. The analysis thus provides qualitative insight, but carry no claims of generalizability.

FRAMEWORK OF UNDERSTANDING

The framework consists of three main elements: First, an understanding of social sustainability to be used to scrutinize the company conceptualisation of its (new) service product. Second, an understanding of the degree of embedding of the concept in a project based organisations. Third, the creation of reference projects communicating the company ability to deliver social sustainability services.

These elements enable a discussion of degrees of social sustainability, leading to a focus on intermediate steps between “*business as usual*” and sustainable business (Parkin 2010) and to establish criteria for rigorous implementation, drawing on Lozano (2013) and others.

Social sustainability

Sustainable urban community development and urban regeneration rest in tensions between multiple dynamics (Imrie and Lees 2014), and have been understood from a series of disciplinary perspectives, such as green building research (Zuo and Zhao 2014) and sociological theories (Frantzeskaky *et al.* 2013). Increasingly however, integrated multidisciplinary perspectives building on the original tripod of economic, environmental, and social sustainability are proposed (Axelson *et al.* 2013, Boström, 2012, Colantonio and Dixon, 2010, Ghahramanpouri *et al.* 2013, James 2015).

Reviewing and synthesizing several perspectives, Colantonio and Dixon (2010) develop a multidisciplinary understanding of social sustainability, defined as how community, society and individual coexist, and how this coexistential environment creates common models for the future, integrating a concern for the global ecosystem (Colantonio and Dixon 2010)

Further, they propose twelve characteristics of a sustainable community, grouped in social, spatial, and economic categories (Colantonio and Dixon 2010, p. 33). The social characteristics of social sustainable environments are active, inclusive, safe, well-served and fair for everyone. The spatial are well-designed and built, well connected centre-periphery, and environmentally sensitive. And the economic characteristics are well run, thriving, with a flourishing and diverse local economy, However they underline that social sustainability is more of a contextual ongoing open ended process, calling for cautiousness in establishing too stable and generic frameworks (Colantonio and Dixon 2010). Adding to this, Axelsson *et al.* (2013) point at a combination of material and immaterial elements encompassing “*human built objects, landscapes and combined man and nature systems*” as well as immaterial; “*practices, representations, expressions, knowledge, skills, and instruments, objects, artefacts, spaces associated with practices, including tradition, identity, values, cultural diversity, spirituality, and aesthetics*” (Axelsson *et al.* 2013, p 6). Other “*qualifications*” of the definition would be to include reduction of social exclusion (Tasan-Kok *et al.*, 2013), gentrification (Lees *et al.*, 2015), strengthening

empowerment (Fung 2009), access to employment (Ghahramanpouri *et al.* 2013), and reduction of violence (Cozens, 2011)

The contextualization of the social sustainability justifies a look at the Swedish context and its specific understandings (Boström, 2012). Olsson (2012) proposes that social sustainability should encompass welfare, justice and problem-solving capacity. The welfare and justice dimensions overlap completely with the above mentioned, but the problem-solving capacity of a society is new. Olsson (2012) argues that this relies on individual initiative, cultural values, and control mechanisms within, and depending on, societal institutions and politics.

To summarize, social sustainability is composed of multifaceted and emergent elements involving social, spatial, economic and material aspects that should be kept in context and involve local appropriation. Important elements are employment, civic society and physical aspects such as non-violence, buildings and locality. However the concept carries internal tensions and contradictions. This review and in particular the aforementioned characteristics of social sustainability will provides a frame for comparison for the concepts developed by the companies.

Degree of social sustainability implementation in project based organisations

In order to deliver service the contractor need to embed it in its organisation, and not only in single project. The degree of embedding consists of both structural and agency oriented elements including delivering projects with the social sustainability service and establishing an organisational function responsible for the development of social sustainability and its placing in the corporate hierarchy of a project based company. Large contractors and building firms are often multidivisional and usually exhibit headquarters with a range of corporate functions such as purchasing, finance, accounting, quality, human resources, health and safety and marketing (Bang 2002). This includes corporate social responsibility and CR (Arenas *et al* 2011). However the projects are the more important production unit where the actual balancing of a diverse set of interests and stakeholders occur (Cattani *et al* 2011, Valdez-Vasquez and Klotz 2013). It is therefore within the portfolio of projects that one should find the real embedding of intended business change. Arenas *et al.* (2011) provide an illustrative example of the embedding in the contractors' organisation. A civil engineering contractor company created corporate functions to support the transformation towards sustainability, namely a corporate function of innovation and sustainability as well as a supervisory sustainability committee. The corporate function encompasses sustainability, innovation, quality, R&D and regulation. The sustainability committee supervises policy, objectives and plans in the sustainability and CR areas (Arenas *et al* 2011). However the main transformation of the company occurred in the portfolio of projects, reducing construction projects from three thirds to half of the portfolio, increasing renewable energy projects from four percent to one fourth of the turnover and half of the profit.

Several authors have proposed to understand organisational transition towards sustainability in businesses through stepwise models, depicting it as a transformation of company into an integrated handling of sustainability (Arenas *et al* 2011, Averelo *et al* 2011, Haigh and Hoffmann 2011, Parkin 2010). Haigh and Hoffmann (2011) propose that the future organisation integrating sustainability should be understood as hybrid organisations where the business models blur for-profit and non-profit worlds (see also Kramer and Porter 2011). They (2011) portray traditional organisations as addressing social/environmental issues only if the organization has slack (e.g.,

resources, profit) and a strong business case. Whereas hybrid organisations encompass a business model configured to address explicit social/environmental issues. Likewise Parkin (2010) describes the transformed organisation as no longer distinguishing between economic and sustainability goals as done traditionally with sustainability as part of its reactive corporate (social) responsibility (CR), but integrating and balancing them. Importantly Parkin (2010) proposes to characterise several intermediate steps in the transformation, going from defensive CR, to strategic CR, to “*ambivalent supplication*” to sustainability, to a “*transformational*” phase before reaching the hybrid organisational form Haigh and Hoffmann suggest. Especially the “*ambivalent supplication*” and the “*transformational*” appear relevant in the context of building companies. Parkin (2010:127) summarises ambivalent supplication as “*too fearful to take the transformation plunge –want the helping hand of legislation, but, yet again, perhaps not ready to leave the shores of business as usual*”. The following mechanisms are active in ambivalent supplication: competing strategic priorities, complexity of implementing strategy across business functions, lack of recognition from financial markets and differing definitions of CR across cultures (Parkin 2010). We suggest to fine grain Parkin (2010)-s two phases of “*ambivalent supplication*” and “*transformation*” by looking at first the rhetoric mobilised on social sustainability and to what extent the companies have developed a business concept for providing related services. The process of conceptualising a service for social sustainability can be understood in a similar vein as other business concepts, such as knowledge management (author references) also when it comes to the necessary organisational change. Here Lozano (2013) study of implementation of corporate sustainability provide useful criteria. Lozano (2013), thinks of two elements of the needed organisational change. There are forms of resistance and strategies to overcome them. Both can be understood to potentially operate on individual, group or organisational level. And both can be informational, emotional, behavioural or systemic. Lozano (2013) shows that in three cases of corporate change there are incongruity between the recognised barriers to change and the strategies proposed to overcome them. Conceptualising a business concepts recurrently involves a local, business internal shaping of the general (globally available) concept, both by the provider of the concept and further in concrete cases in interaction with stakeholders.

Providing reference projects

Winning and carrying out building projects with social sustainability would transfer rhetoric into a more concrete form of reality. When implementing a new business concept it is common place to develop reference projects for obtaining more projects (Karim and Strzelecki 2012). Valdes-Vasquez and Klotz (2011) provide an understanding of such first projects and point (back) to corporate social responsibility and stakeholder management as tools in building processes for construction projects.

The quest for winning early reference projects is also apparent in the firms marketing efforts. Project-based companies can be characterised as having three types of marketing (Cova *et al* 2002). The first is mostly reactive and involves responding to invitations (call for tenders), but also to anticipate these. The second, called the constructivist (Cova *et al* 2002), focuses on creation and redefinition of the companies' service offers. The third, network-based marketing builds the company's reputation through interacting on personal level with other professional players in the sector (Graham 2012).

Reference cases are according to Karim and Strzelecki (2012) often used by professional service providers to overcome the intangible feature of services. The use of references is believed to serve the purpose of increasing credibility, being helpful in convincing potential clients about the company's abilities and quality offerings letting reference cases for example exhibit well known clients (Karim and Strzelecki 2012).

Summarising the framework

The challenge for contractors engaging in social sustainability is to gap a business approach focusing on the possible financial benefits today and a social approach aiming at long term possibly intangible results. The framework of understanding consist of the following main elements; having a concept, embedding it in the organisation and developing reference cases. The first involves formulating a foundation, making a concept of social sustainability suitable as project service offering; Second establishing an organisational function responsible for nurturing the development of social sustainability and its placing in the corporate hierarchy of a project based company; And third shifting from reactive to constructivist marketing of social sustainability. We will focus in particular on reference cases. These elements are then used to characterise the degree of social sustainability.

A CONTRACTOR MOVING TOWARDS SUSTAINABILITY?

Below the case is presented, and the analysis done in the subsequent discussion section, where the other studied Swedish contractors are drawn upon. The contractor has four main business areas and operates in Sweden and abroad.

Business concept

The contractor formulated an entire comprehensive concept for the development of deprived areas and launched it in 2011. The launch was followed up by further marketing efforts to publicise the concept. This concept is integrated in the strategy of the contractor along with a number of other concepts, appearing in the annual reports the subsequent years. It claims to be holistic encompassing environment, social and economic sustainability such as building- and energy technological solutions, financing alternatives, safety and more jobs in areas of building when in need.

The concept was integrated in the strategy to strengthen stakeholder relations. The company initially carried out a stakeholder dialogue on sustainability. This was juxtaposed in an analysis of issues of importance, where energy efficiency, ethics and law compliance had high priority, whereas social sustainability is not mentioned and contributions to societal development are moderately important.

Resources were also allocated to further development of the concept over the next three years with a focus on the efficiency to produce buildings and/or renovate them. By 2015, the concept is still part of the public communication of the company.

Embedding social sustainability in the organisation

In a period the CEO was also manager of sustainability which was placed as a support function in the headquarters. The project was supported by a five persons sustainability council amongst which the human resource and one of the business unit managers participated. A responsible for the concept was appointed.

The company also carried out various corporate social responsibility activities such as sponsoring youth associations. The policy being that the sponsorships should focus on societal effects, development of society, communality and teambuilding. The company also introduced sustainability annual reporting in the same period. However

after just a few years the company reorganised its new built business area, due to drop in turn over. The reorganisation reduced the higher echelons both at the corporate and regional levels. The sustainability function was not affected by this reorganisation, but the manager responsible for the concept was moved to another position.

Reference Cases

The reference cases on the website involves a broad set of corporate social responsibility activities but no direct reference to the comprehensive concept mentioned above. The company annual “*sustainability report*”, which is a separate document of the annual (business) report, tells about a small town in the outskirts of Stockholm where the contractor has built some 100 ownership apartments hiring 25 unemployed persons. This is described by the contractor as being in the “*spirit of economic and social sustainability*” (the annual sustainability report). The concept was announced to continue with the building of more apartments. Two projects were announced in 2012, but no results communicated. On the contrary, by 2014 there appears to have been internal disagreement on the usefulness of the concept for running project and its marketing properties. Concerns were raised regarding the costs of realising the concept entraining rents' increase of apartments, which in turn would risk leading to social segregation. These concerns however had anticipatory character and were not linked to concrete project experiences. The concept did appear to lack ownership after the reorganisation. The projects presently operated by the contractors, are according to interviewees at managerial level developing in other directions. Moreover internal knowledge sharing through experience exchange databases is not supporting the social sustainability concept sufficiently to make it appear doable for new interested project managers.

DISCUSSION

The discussion starts with the development of contractor 1. It then it juxtapose this with the two other contractors in three dimensions of business concept, placement in organisation and reference cases.

Evaluating the contractor 1's concept, its integration and progress

The presented case shows how contractor 1 took important steps to deliver a social sustainability service. The business concept, the embedding in the organisation and the first reference project all came in place. The concept involves social dimensions, yet does not covers the range of topics suggested by Colantiono and Dixons (2010) definition. Moreover a number of barriers for the internal embedding were active, on individual, group and organisational level (using Lozano (2012)-s concept). Bergendahl and Käll (2014) thus point at a series of factors including lack of motivation among middle and lower levels' staff. According to interviews the project managers found it hard to use the concept, which became portrayed as lacking concrete content and at a time too inflexible for the single project. Bergendahl and Käll (2014) conclude that the concept became primarily a vehicle for marketing.

These signs of internal resistance appear quite classical for top down change in project based organisations. They reveal multiple internal cultures of interpretation. Compared to Parkins' steps the move forward towards social sustainability placed the company in the ford between business as usual and sustainable business. The ambivalent supplication exercised was however asymmetric and uneven in terms of differences for diverse parts of the organisation for various projects and even in relation to the continued strategic priority to other types of sustainability and to corporate social responsibility.

Comparison with the two other: Business concepts

Only contractor 1 has communicated a concept with holistic social sustainability, encompassing environment, social and economic sustainability. Contractor 2 has a concept that communicates a lot of other concerns than social sustainability, such as cost efficient synergies between renovation, energy efficiency and maintenance. Contractor 3-s business concept for sustainable renovation focuses on energy savings involving project management, real estate management, installation, environment, certification and energy as important, and does not mention social sustainability.

Social sustainability in the organisation

All three contractors have managers in charge of sustainability placed in top corporate management board, but the strength of this placement differs. In the first case it was the CEO; in another it is a manager of several support functions, one being sustainability. In the third the priority is recent, giving the sustainability manager a seat in corporate management, showing that sustainability moves up the agenda. However priority to sustainability does not imply priority to social sustainability.

Reference cases

Where Contractor 1's reference case involves local employment in the building phase the Contractor 2-s reference cases focus on energy efficiency and close stakeholder involvement. Contractor 3's only reference case is organised to highlight the three classical aspects of sustainability. The reference case appeal more to other less deprived areas, risking to contributing to gentrification and indirect segregation. It is mostly adult tenant representatives who participate, counter to the age profile of the suburbs (Andersson *et al.*, 2009; Valdes-Vasquez and Klotz, 2011). Controlled participation is parallel to many other urban renewal projects (Valdes-Vasquez and Klotz, 2011). Resources have thus been invested in the corporate headquarters developing reference cases and to communicate them as done here. These efforts contribute to render the companies more attractive and societally reliable and responsible. A profile that might impact on for example recruitment of employees.

Compared to Parkin (2010)-s steps of sustainable leadership these companies can be said to exhibit an “*transformation*” in terms of engagement in sustainability and an “*ambivalent supplication*” vis a vis social sustainability. As the present analysis is taking a contemporary status only, it is difficult to evaluate whether internal different priorities and or common interpretations of clients' will to purchase the concept might explain the status. But it is a clear implication that social sustainability has to be developed from several positions inside and outside company.

CONCLUSIONS

This paper has investigated how social sustainability can become imbedded or not in contractors services as part of the community strive towards balanced sustainability in urban renewal. Drawing on more strands of research literature, social sustainability was conceptualised through a set of criteria and its implementation as a service product understood as developing a business concept, embedding it in the project based organisation and developing reference cases. The three studied contractors were all large, operating on the Swedish market and assumed to be market leaders in social sustainability. However only one of the three contractors, contractor 1, had a “*full*” sustainability concept for a short a period, before it almost disappeared again. This service concept had a clear integration of social sustainability, aiming at doing social responsibility with new initiatives such as offering jobs to the residents during the renovation process and/or designing the dwelling so that its covers inhabitants needs

through the different periods of their life. The two other contractors, in contrast, communicate more energy efficiency oriented concepts and barely touch upon the social sustainability issue. So far the set of projects on social sustainability appears to be few and with a relatively limited understanding compared to a full blown conceptualisation of social sustainability. This could be because they evaluate what can be economically feasible to do as service project in this area, interpreting the economic conditions, and/or reflecting internal resistance and disagreement on the priority of the subject. Thereby the three contractors appear to show the clear limitation of translating a societal social concern into business concepts. They sit between two chairs. To create social sustainability requires a broader long societal alliance. As contractors contributions might be very valuable as part of such an orchestrated public- private effort, this seems to be a likely way forward.

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BARRIERS TO SOCIAL ENTERPRISE IN THE UK CONSTRUCTION INDUSTRY

Martin Loosemore¹

University of New South Wales, Faculty of the Built Environment, Sydney, Australia

Given recent trends towards social procurement in many countries, it is surprising that there has been no research into social enterprise in the construction sector. In-depth interviews with twelve senior representatives of UK social enterprises indicate that social entrepreneurs face significant barriers to operating in the UK construction industry. Respondents perceive that the vast majority of the construction industry is ignorant, mistrustful and resistant to engaging with social enterprises. Traditional monetary perceptions of value, established supply chain relationships and biased procurement practices are just some of the barriers which exist. Recommendations are made to reduce these barriers which will involve: incentivising social enterprise through the adoption of social procurement policies; reducing bureaucracy in tender processes; opening up rigid supply chains; unbundling trade packages; building effective partnerships and social enterprise networks; challenging negative perceptions of social enterprise; and overcoming strong path dependencies and resistance to change.

Keywords: corporate social responsibility, community, innovation, social enterprise, social procurement.

INTRODUCTION

A recent report by the UK's Equality Trust (Equality Trust 2014) shows that the UK is an increasingly divided country with a growing gap between the rich and poor and that this was contributing significantly to rising unemployment, health and social problems and to a lack of trust and cohesion in UK society. LePage (2014) argues that traditional government welfare systems, charities, not-for-profits and voluntary organizations are being overwhelmed with the sheer scale and complexity of the challenges posed, leading the UK Government to call for a paradigm shift in welfare provision which brings more commercial and entrepreneurial thinking to the table. A new 'social economy' is emerging to take advantage of this new opportunity and was recently defined by International Labour Organization as including any "*specific forms of enterprises and organizations. Cooperatives, mutual benefit societies, associations and social enterprisesthat all promote and run economic organizations that are people-centred*" (Fonteneau *et al.*, 2011:1). Social enterprises represent the fastest growing part of this social economy. What makes social enterprises different to other organizations in the social sector is that they trade for a social purpose, feeding their profits back into the disadvantaged community groups they are set up to serve (Villeneuve-Smith and Chung 2013).

The construction sector represents a major opportunity for the emerging social enterprise sector since it employs more people than any other industry and has a

¹ m.loosemore@unsw.edu.au

significant impact on the fabric and prosperity of the communities in which it builds (WMI 2010, GCP 2013). In UK the construction sector contributes around 7.4% to national GDP, employs around 2.04 million people directly and could potentially employ up to 10% of the 1 million 16-24 year olds currently unemployed in the UK (Chevin 2014). Furthermore, given the construction industry's extensive linkages with other sectors in the economy, the potential economic multiplier effect of one job created in construction into other sectors of the economy is huge. According to CBI (2012) points out, the UK construction sector generates £2.84 of total economic activity for every £1 spent on construction. As Hansford (2013) noted, at its best construction can have a transformative impact on local communities, regional economies and national prosperity by enhancing the urban fabric and acting as incubator zones for new business, innovation and education and ultimately inward investment and economic growth.

In addition to representing a significant opportunity for social enterprises, there are many mutual benefits for the construction industry to engage with this emerging sector. Outside complying with corporate social responsibility objectives, the emergence of the social enterprise sector in the UK is being driven by a number of important public sector trends and initiatives which directly impact on construction. Of particular importance is the government's move towards outcomes-based commissioning and new social procurement legislation such as the Public Services (Social Value) Act 2012 which encourages a broadening of public procurement criteria to encompass 'social value' in the assessment of construction project tenders.

Given the importance of the public sector as a construction client, social enterprises represent an innovative opportunity to meet these new social value requirements since they specialise in delivering social value to the communities in which they work. However, these trends raise new and important challenges for the construction industry which have not yet been addressed in the construction management research literature. In particular, how do firms in the construction sector engage more effectively with social enterprises as a way of meeting these new social procurement requirements? The aim of this paper is to address this question through in-depth interviews with social enterprises which have worked in the construction sector.

SOCIAL ENTERPRISE

Much of the literature in the field of social enterprise has been consumed with finding a precise definition for the term. Nicholls (2010) argued that the field of social enterprise was still in a pre-paradigmatic state, lacking an established epistemology and Grassl (2012:37) asserted that "*terminological profusion and confusion and underlying conceptual vagueness*" still plague the field. While Doherty *et al's* (2014: 430) recent review of the social enterprise debate argues that the field of social enterprise had "*matured beyond definitional debates*", it remains the case that the term social enterprise is often misunderstood. So for the purposes of this paper, PWC's (2011:1) definition is adopted - as an organisation which "*combines the passion to solve social and environmental issues with the power of commercial enterprise.*"

The social enterprise sector around the world is growing rapidly. Villeneuve-Smith and Chung's (2013) survey showed that in the UK there were over 70,000 social enterprises employing around 1 million people and contributing over £24bn to the economy. In the EU, the social enterprise sector now accounts for over 6.5% of aggregate employment (Monzon and Chavez 2012). Social enterprises take many

forms and operate in many sectors. However, the construction industry is deeply under-represented in the social enterprise sector given its relative size and impact. For example, in the UK Villeneuve-Smith and Chung's (2013) survey of social enterprise activity shows that apart from housing (which is dominated by Housing Associations), social enterprises that work in the construction sector are conspicuously absent. Similarly, in Australia, Barraket *et al*'s (2010) survey of 365 social enterprises indicated that the social enterprise sector is focussed in education and training (41.6%) and recreation services (31%). Social enterprises operating in the construction sector featured in the least represented areas at around 2% of the population. Similarly, in the US, Clark and Ucak's (2006) survey of 211 social enterprises found most were focussed in the energy, environmental and technologies sectors (19.4%) while fewest were represented in manufacturing, construction and transportation sectors (8%). The relatively few social enterprises that do currently operate into the construction sector tend to be very small start-ups and appear to be restricted to cleaning services, gardening and landscaping services, facilities management, concierge services, small works and grounds maintenance and environmental services such as waste management and recycling. While there are many more inspirational social enterprises operating in the construction sector around the world, these types of small firms would typically operate a long way down the construction supply chain, largely out-of-sight and out-of-mind and in a notoriously high-risk environment. For example, Blue Sky is a successful UK social enterprise which focusses on offender rehabilitation by tendering for commercial contracts in grounds maintenance, painting, landfill, tree planning, recycling and some non-construction-related work and then delivering the contracts by employing ex-offenders. David Cameron, The UK's Prime Minister, wryly described Blue Sky as the only company in the UK where you needed a criminal record to get a job. In Australia, BoysTown Enterprises is a social enterprise linked to a charity which was established in 1999 as an Intermediate Labour Market (ILM) organisation to employ disadvantaged and Indigenous young people in paid employment as a means of developing work based skills and moving them from welfare to work. BoysTown Enterprises recently successfully branched out into speculative residential construction work and since 1999 has employed over 2,000 disadvantaged youths. In the US, KaBOOM! is a US social enterprise which helps communities build their own children playgrounds. KaBoom! has raised over US\$200 and encouraged over 1 million community volunteers to build more than 2000 playgrounds in under-privileged areas in the US which serve more than 5.5 million low income children.

There is a substantial body of research into the barriers that face social enterprises in many other industry sectors. For example, Doherty *et al* (2014), Villeneuve-Smith and Chung (2013) Kernot and McNeill's (2011) analysis of social enterprises in the US, UK and Australia reveal many day-to-day challenges which include: a focus on day-to-day survival preventing long-term strategic planning; developing an independent income stream from trading activities; establishment problems in limited legal and financial structures; overcoming negative perceptions and a misunderstanding of the risks and opportunities of engaging with social enterprises and an inability to compete with mainstream businesses. In contrast, there has been no research into social enterprise in construction and while a few large firms are starting to engage with social enterprises, there seems much scope to expand our understanding of the challenges they face and of how the construction sector can engage more effectively with its growing but fragile social economy. A review of the Association of Researchers in Construction Management (ARCOM) data base

(<http://www.arcom.ac.uk/abstracts-search.php>), shows only one reference to social enterprise in over twenty five years (Tobi and Amaratunga 2010), which usefully focused on facilities management but did not explore barriers to entry.

METHOD

To explore the barriers to entry for social enterprises in the construction industry, semi-structured interviews were conducted with the leaders of twelve successful social enterprises trading in the construction industry. The social enterprises were randomly sampled from the growing number of social enterprise directories which are beginning to emerge in this country. These include the Social Enterprise UK 'Buy Social' Directory, the 'Social Enterprise Mark' directory, Social Firms UK 'Just Buy' Directory, BuySe.co.uk directory and the Wates Group directory of approved social enterprise suppliers. The people and case study social enterprises which were investigated are listed in Table 1.

Table 1: Sample details

Case study	Respondent	Description of activity
1	Criminal Justice Lead	Recruits and trains offenders and ex-offenders in and out of custody, providing them with nationally recognised construction industry qualifications, work experience and direct employment in painting and decorating, tiling, dry lining and other areas.
2	Director	Provides facilities and estate management services, drawing its staff from local communities and public housing tenants who are disadvantaged in the labour market.
3	Managing Director	Saves resources by rescuing and re-using waste timber that would otherwise be landfilled or wood chipped and creating sustainable jobs, as well as training and volunteering opportunities, for local disadvantaged and unemployed people.
4	Managing Director	Creates local job and training opportunities for disadvantaged and unemployed and to stimulate local economic regeneration by delivering construction trades services such as external wall insulation, plastering, tiling, painting and general contracting.
5	Operations Manager	A crewing and logistics social enterprise which employs people with a history of homelessness.
6	Director	Delivers commercial and residential grounds maintenance, horticultural and waste services with the aim of supporting people with mental health conditions into mainstream employment, getting them off benefits and to reducing their reliance on medication.
7	Sales Executive	Provides employment opportunities for disabled people through surveying, design, manufacturing and subcontracted installing services for PVCu windows and doors and kitchens and bathrooms.
8	Executive Director	Helps young people from disadvantaged backgrounds, ex-service leavers and ex-offenders build confidence and gain

	and Researcher	access to training, education and employment opportunities in the construction industry.
9	Managing Director	A recruitment agency that specialises in construction menial workers, trades and professionals and focusses on employing people from disadvantaged backgrounds (particularly long term unemployed, ex-offenders, disabled and displaced apprentices).
10	Managing Director	Assists in regional development in deprived communities by influencing planning to improve housing and regeneration strategy to create opportunities for local disadvantaged people. It also provides disadvantaged groups with training, apprenticeships, recruitment, support and sustainable employment opportunities.
11	Executive Director	Works to prevent and alleviate youth homelessness and unemployment through property maintenance services to both private and commercial clients drawing employees from former homeless and at risk young people.
12	Director	Provides wood waste collection and recycling services to the construction industry and community and socially inclusive volunteering and learning opportunities to disadvantaged people in its local community.

The semi-structured interviews were designed to explore the challenges that social enterprises face in growing their businesses in the construction industry. To supplement the interview data a documentary analysis was also undertaken of publically available and supplied information relating to each social enterprise's business strategies and activities. The data from these interviews and documents were analysed using content analysis to identify common themes which emerged from the interview transcripts. The coding framework was developed from a detailed review of the literature relating to social enterprise outside the construction sector.

RESULTS

The major challenges identified by respondents in engaging with the construction sector are discussed below.

Negative perceptions

Respondents pointed to a lack of trust and not being taken seriously by the construction sector. There was a strong perception that social enterprises were seen as charities that deliver low quality services for a higher price than traditional subcontractors and suppliers and that they did not have the capacity to handle large work packages. For this reason, most social enterprises found themselves working on small packages at the very bottom of the supply chain which prevented them growing their business to enable them to tender for the larger packages in the future.

"It can often be challenging for contractors to make the mind-shift from treating us like a charity to treating us like any other business. We don't want to be treated like a charity". RESP # 12

“Social enterprises are not taken seriously by the construction industry.... on most occasions it’s just a ‘tick the box’ exercise. We tend to get given token contracts which represent tiny parts of the overall contracts”. RESP # 7

Resistance to change

Every respondent pointed to an unwillingness or inability in the construction sector to change established supply chain relationships and procurement practices. The industry was seen as very close-knit with long-established supplier networks, recruitment methods and sources of labour (old boy's network). These relationships and networks were very difficult for most social enterprises to break-into.

“The industry is very close-knit. The people who work in the industry don’t tend to leave the industry which does bring many benefits but it can also hold the industry back in terms of the resistance towards change” RESP # 8.

“The construction sector has not been the most enlightened and forward thinking group of people. They have been doing things the same way for a long time and it’s been hard to get them to adapt their practices to do something different” RESP # 12.

“It’s difficult to break into the construction industry because the big firms have their established subcontractors. Supply chains seem to be locked-in and the typical response is that “we always use X”. RESP # 7

Existing procurement practices

Respondents also pointed to complex, inconsistent and bureaucratic procurement procedures which they felt placed an unfair administrative cost burden on them. There were also perceptions that the construction industry had a narrow view of ‘value’ (price) which under-values what social enterprises can contribute.

“The construction industry is also dominated by very large international and national companies who prefer to make one phone call and sort out their supply chain. There is not always willingness, for reasons of efficiency and risk to split that supply across various suppliers”. RESP # 7

“We have learnt not to wear our heart on our sleeve. The industry is not impressed with such stories. The industry is driven by two main things: price and quality of service. The first question you have to get past before even discussing social enterprise is whether you can do it cheaper..”. RESP # 2

Regulations

Respondents identified the highly regulated nature of construction activity (compared to other industries) as a significant barrier to entry. Complex pre-qualification processes, tender registration, quality assurance and health and safety requirements can be prohibitive and daunting for social enterprises with minimal resources and experience of the construction sector.

“The construction sector is heavily regulated for obvious practical reason which consumes much time and resources for a small business.....and it takes a while to become familiar with these special requirements”. Resp# 5

“Construction is a heavily regulated sector for us. There are many hoops to jump through and procurement systems are complex and burdensome. When your income is only 1% of your turnover and your turnover is only a few hundred thousand pounds, you can’t afford to pay to be on tender lists or tender for many jobs without a guarantee of work”. Resp#11

The project based and cyclical nature of construction activity

Many respondents argued that the project-based nature of work in the industry leads to short-term thinking which de-values what social enterprises offer and short-term contracts which prevent stable work flows and employment opportunities for their beneficiaries. The cyclical nature of the construction market *also* makes it hard to work across different organisations in a coordinated way.

“Being married to the construction industry has been difficult. We really struggled in the 2008 crash. The construction sector is highly cyclical and you have to be agile, flexible and resilient if you are to ride the ups and downs”. RESP # 11

“The industry is peripatetic. You build up a relationship with someone and then they move on. This is especially problematic if you are dealing with the industry at a local level”. RESP # 4

Construction industry culture

Finally, cultural issues, preconceived ideas about the ideal construction worker (able bodied males) and ingrained stigmas associated with disadvantaged groups were seen as key barriers to engagement.

“There is a strong perception in the industry of where the workforce should come from... People get jobs because they are known, know someone or come from a certain background. Introducing new people into that system is difficult”. RESP # 4

“There are cultural barriers that revolve around expectations of roles for certain types of employees.....There are many other barriers around issues like ethnicity and ex-offenders etc” RESP # 8.

DISCUSSION

The results align with Newth and Wood’s (2014) research which suggests that resistance to implementing a social procurement policy is likely to come from four main areas: organisational – governance, risk appetite, resources and culture; market – maturity, resistance, competition and diffusion challenges; formal institutions – contracts, systems and practices; and informal institutions – organisational habits, norms, customs, routines and power structures. The results also support Erridge (2007) who argued that in most industries the concept of ‘value’ is still dominated by market based language (value for money) and this is certainly reinforced by Loosemore and Richard’s (2015) critique of value in the construction sector.

In terms of strategies to engage more effectively with the social enterprise sector, this research indicates that Bonwick’s (2014) suggestions may be useful. These include the development of: more visible social enterprise supplier networks; more research on best practice in engaging social enterprises; better networking opportunities for social enterprises; better training for those involved in the social procurement process; better communications about the benefits of social procurement; better incentives for business to engage with social enterprises; more partnerships between business and the social enterprise sector; and encouraging and supporting social enterprise certification. LePage’s (2014) also highlights the importance of leading firms in any industry taking a leadership role to change existing procurement practices, to develop better policy, practice and internal capabilities and skills to support it and to create better social impact measurement tools to quantify outcomes and impacts.

This research also provides a number of new construction-specific insights into what firms in the construction industry need to do to support and improve their engagement with the growing social enterprise sector. First changes to traditional procurement practices are required. They need to be simplified and standardised and large work packages which are beyond the capacity of small social enterprises need to be unbundled. Construction firms also need to ensure that social procurement initiatives developed in head office get implemented on site and better networks, partnerships and alliances between large firms and social enterprises are needed to support the sector's development and enable social enterprises to break into existing and well-established supply chains. Importantly, perceived negative attitudes towards social enterprises in the construction sector need to change by working more closely with social enterprises and by better education of clients, companies and supply chains about their potential benefits. This can be helped by the development of a clear and transparent social procurement policy which communicates a clear rationale and commitment to social enterprise. Clearly identifiable and measurable targets and goals also need to be set and underpinned by clear and practical guidelines, systems and procedures and requirements (such as social clauses) to enable social value considerations to be integrated into tenders, contracts and procurement decision-making. This will help to broaden concepts of value in the construction sector.

Finally, respondents pointed to a lack of trust and not being taken seriously by the construction sector. There was a strong perception that social enterprises were seen as charities that deliver low quality services for a higher price than traditional subcontractors and suppliers and that they did not have the capacity to handle large work packages. For this reason, most social enterprises found themselves working on small packages at the very bottom of the supply chain which prevented them growing their business to enable them to tender for the larger packages in the future.

CONCLUSION

The aim of this paper was to explore the barriers to entry for social enterprises in engaging with the construction industry. Clearly, it has presented these barriers from the perspective of social enterprises only and the findings presented above need to be balanced with insights from the contracting sector that employs them. For example, the unbundling of subcontracts into smaller packages could impact upon competitiveness by reducing economies of scale. Furthermore, legitimate questions might exist in the contracting sector about divided social enterprise loyalties to their beneficiaries or clients. Nevertheless, this research does provide some new insights into perceived barriers to entry which might prevent the construction industry engaging with the growing social enterprise sector. By addressing these barriers, research in other fields indicates that the industry will be better able to contribute to the communities in which it does business and to play its role in addressing growing social inequities by helping the most marginalised and disadvantaged people in society. It is clear that many of the challenges identified by this research are common to social enterprises outside the construction industry. However, this research also shows many construction-specific challenges and by doing this contributes to the literature in both mainstream social procurement and construction procurement research. Recommendations are made to address this lack of understanding and engagement which involve: changing negative perceptions; building mutual understanding and trust; overcoming strong path dependencies and resistance to change; addressing biased procurement practices; reducing costly bureaucracy;

opening up rigid supply chains; building effective partnerships; and ensuring that firms take their CSR responsibilities seriously.

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AN EVALUATION OF CONSTRUCTION PROFESSIONALS SUSTAINABILITY LITERACY IN NORTH WEST ENGLAND

Anthony Higham¹ and Craig Thomson²

¹*School of the Built Environment, University of Salford, Salford, UK*

²*School of Engineering and Built Environment, Glasgow Caledonian University, Glasgow, UK*

Sustainability represents the UK construction industry's most important and indeed challenging issue, placing it at the forefront of both current debate and government policy. As pressure increases on the industry to embrace its principles, a radical shift is required in the awareness, understanding and cultural acceptance of its potential benefits. Whilst a shift is slowly being realised at a strategic level, delivering sustainable construction in practice remains a challenge. Not least due to a lack of sustainability awareness and engagement amongst construction professionals revealed by successive quantitative surveys, and a need to raise sustainability literacy levels. In an attempt to understand why construction professionals give so little credence and genuinely struggle to attain sustainable construction in practice, eight in-depth semi-structured interviews were conducted in North West England. The research explored their awareness, understanding and literacy levels of sustainability and how this impacts their ability to deliver the concept at both theoretical and applied levels. Findings suggest that whilst practitioners exhibit a strong awareness at a theoretical level, this often is highly individual in interpretation promoting inconsistency within and across projects. At an applied level, construction professionals observed a gap in the application of the sustainable construction in practice due to 1) a tick box mentality enshrined in sustainability appraisal tools such as BREEAM; 2) an isolation from key decisions related to sustainability, and 3) a lack of awareness amongst client organisations. The research concludes by proposing further data collection to both expand the sample and contrast these preliminary findings with professionals who desire a more sustainable model of delivery.

Keywords: construction professionals, learning environment, sustainable construction, sustainability literacy.

INTRODUCTION

Sustainable construction has emerged as a clear agenda over the past decade and is driven by a desire to realise the potential economic, social and environment benefits from a more efficient and sustainable construction industry (Pearce 2006). In the UK, this agenda has been supported by a number of strategies emphasising the industry's role in delivering national climate change and sustainable development targets: UK Sustainable Development Plan (2005); Sustainable Procurement Strategy and Action Plan (2006); Sustainable Communities Plan (2003); the Low Carbon Transition Plan (2009); culminating in the revised Strategy for Sustainable Construction (2008). Sustainable construction brings a previously disparate agenda together under a

¹ A.P.Higham@salford.ac.uk

common framework where climate change and traditional issues of environmental sustainability, are considered alongside economic sustainability (i.e. contribution to the wider economy, Considerate Contractors and Corporate Sustainability) and wider societal issues (i.e. quality of life, well-being, equity and social justice). The likes of Rees (2009) recognise the need for radical change in professional practice, requiring a promotion of greater integration in the project process and the adoption of a whole-life view of a building which considers its implications for the three sustainability pillars (i.e. environmental, economic and social).

The need for change is apparent, and the UK government have demonstrated a desire to progress the agenda through their own construction procurement strategies (HM Government 2011; Berry and McCarthy 2011); the revision of planning requirements and application of Code for Sustainable Homes in England, Wales and Northern Ireland and BREEAM for non-domestic buildings, changes to building regulations in England and Wales (Part L) and Section 7 in Scotland. With around 40% of construction procured through the public sector, a focus of spreading sustainable practices into the wider construction industry through public procurement and reflected in its promotion within major projects such as London Olympics 2012; Glasgow Commonwealth 2014 Games and CrossRail. Indeed the Construction 2025 Industrial Strategy (BIS 2013) cites a clear objective from policy makers for UK construction industry to emerge as a market leader in sustainable construction.

LITERATURE REVIEW

Readiness of construction professionals to respond

Despite this, it is clear that the ability of the industry and its professionals to respond to the scale of the problem advocated by the likes of Rees (2009) and achieve the pace of change proposed within Construction 2025 Industrial Strategy has been questioned by high profile reviews citing a chronic skills shortage and a lack of sustainability literacy amongst professionals as key barriers (BIS 2010). Recognition has emerged that this change will not occur organically with a number of surveys amongst construction professionals citing an inherently low level of understanding amongst construction professionals of the implications of sustainable construction on their role, and how practice needs to evolve (CIOB 2013; Dixon *et al.* 2008). Many decisions related to delivering sustainable construction are often counter intuitive to traditional practice and to overcome this construction professionals require education around the rationale and wider implications emerging from these decisions. This appreciation is important to deliver the cultural shift required to move sustainable construction away from being viewed as an enforced agenda and to instead view it as an aspiration for projects (Thomson and El-Haram 2014).

Despite increased investment to up skill construction professionals in green and sustainable technologies and practices, it is questionable as to whether current training programmes and learning practices are sufficient or appropriate to meet the challenge ahead. Whilst acquiring specific skills is important, it is clear that a suitable learning environment is required for construction professionals in order to help change the mindset. Hansmann (2010) writing about the development of sustainable education argued that sustainability literacy is key for professionals to recognise their role in its delivery and then to provide a stimulus for acquiring the necessary skills and appreciation of new technologies and techniques. Unless professionals are sufficiently literate in the holistic nature of its principles, view it through a multi-disciplinary lens and can relate to its often specific language, they are going to

struggle to be able to reflect on its implications for their own role within construction practice.

Emergence of sustainability literacy

Sustainability literacy starts with an appreciation that our current mode of production and way of life is inherently unsustainable with far reaching immediate and long term implications on economy and society (Orr 2004). Stribbe (2009) argues that people need to survive and thrive in challenging conditions and that they need the skills and attributes to demonstrate ecological intelligence and technological appraisal whilst appreciating that there is no one right way. A review of the theory reveals two levels of learning required to raise literacy levels. The first relates to a need for a holistic, multi-disciplinary appreciation of the core principles and implications of sustainability on decision making (Dawe *et al.* 2005) and the second focuses on the importance of experiential learning (Kolb 1984) and that real life understanding is required for its implications. The following section looks at how well equipped current learning within construction is to support these two levels.

Current learning environment for sustainable construction

Dixon *et al.* (2008) reported on a survey of RICS professionals highlighting a stubborn low level of awareness and understanding of sustainable construction, a trend shared by surveys of other professionals over the last decade by Dale (2007), CIOB (2013) and RIBA (2014). Professional bodies over the last decade have sought to foster sustainable construction within their professional competency frameworks, developing associated CPD programmes for their members and have established it as an integrated requirement for their accredited degree programmes aimed at ensuring new graduates are sufficiently literate (Murray and Cotgrave 2007). Hansmann (2010) argues that other disciplines started to evolve their sustainability degree level curriculums in the 1990's but it took another decade before built environment disciplines systematically embedded sustainability within their higher and further education provision. Trade associations are moving to increasingly facilitate awareness of sustainable construction practice and technologies with provisionally accredited formal education through CPD (Gleeson and Thomson 2012). Yet as Gleeson and Thomson (2012) espouse, promoting sustainable construction is as much about changing the mindset and culture of its professionals as it is about developing skills to implement the technologies and new techniques. A question exists as to whether the current formal approaches to learning remain skills based and fail to provide professionals the holistic understanding necessary to change the mindset and culture. It is clear that on its own formal learning remains insufficient to achieve the levels of change advocated by the likes of Wostenholme (2009) and recently within Construction 2025 (BIS 2013).

Concern exists for construction professionals who have not been engaged in formal education in the last decade (or even at all) and have limited access to sustainability related training or professional CPD, as to their ability to achieve the necessary sustainability literacy. Learning within construction is primarily rooted in experiential learning (Kolb 1984) focused on learning by doing through informal pathways to education associated with apprenticeships, work shadowing, peer support and communities of practice which also promote mutual and social learning (Mathur *et al.* 2008). A question exists as to whether these often individually driven learning pathways effectively foster sustainability literacy.

Existing professionals with busy roles are faced with limited opportunities to engage with formal learning environments, and instead rely on specific guidance from literature, schemes such as BREEAM or even outsourcing responsibility to sustainability consultants (Schweber, 2013). Schemes such as BREEAM play a significant role in raising sustainability profile and performance within the industry but that through its often prescriptive and checklist format that, it has been argued, fails to educate professionals beyond compliance (Fortune, 2008). It is failing to provide the depth of understanding to encourage professionals to question the agenda and its implications, or to understand the reasoning for some of the best practice being recommended to them. Therefore concern exists that this is not raising sustainability literacy levels sufficiently, and on its own whilst raising performance levels will not facilitate the cultural change required (Murray and Cotgrave 2007). The potential for change is highlighted by a recent NBS survey (NBS 2014) arguing that 4 out of 5 professionals consider personal belief and values as the primary motivation for the promotion of sustainable construction practice. The RIBA (2014) suggested that personal commitment is more powerful than regulations, client demands, and company policies as the main driver. An approach is sought which provides construction professionals understanding and challenges them to revolutionise their approach by placing sustainability as the core objective from the outset and to move away from a perceived struggle to adapt conventional practice in a way that is merely 'less unsustainable' (Rees 2009).

The literature highlights the combination of a chronic skills shortage and lack of sustainability literacy as fundamental barriers to the evolution and growth of the UK construction industry. Whilst theory reveals two levels of learning through which sustainable literacy could be enhanced with successive surveys contributing little to our understanding of where UK construction professionals sit on this learning continuum. Further work is therefore needed if we are to understand the extent of the sustainability literacy challenge and devise strategies to overcome it.

RESEARCH DESIGN

The research reported, set out to explore the extent to which construction professionals are sustainability literate by examining whether the current learning environment for promoting sustainable construction is sufficiently supporting an appreciation of the holistic principles of sustainability, and experiential learning through formal and informal learning pathways. Research is required to explore whether current approaches based on promotion of best practice and focused development of specific skills, is failing to sufficiently engage professionals in the principles and implications of sustainable construction for their practice. To meet the objectives, the phenomenological paradigm was adopted, making use of an inductive research strategy supported by a survey methodology based on in-depth interviews.

Data collection and analysis

The research reported in this paper represents the first stage of a broader study, and presents the findings of eight in depth interviews with a range of construction professionals, from the North West of England. To achieve a balanced view participants were selected using discriminate sampling, which maximises the opportunity of relevant data collection from a small sample. Details of the sample are outlined in Table 1. Participants were invited to take part in a semi-structured interview held at their office and lasting approximately 45 minutes.

The interviews sought to establish the key thematic areas from which a broader research agenda can be established. Interviews focused on sustainability awareness levels, challenges of current practice and establishing a suitable learning environment for promoting sustainability literacy. The interviews were recorded with the consent of participants, fully transcribed and loaded into Nvivo qualitative analysis software before being thematically analysed. Open coding was used to identify sub-categories associated with the central themes outlined above. Once a large number of nodes were identified, axial coding revealed relationships between nodes and sub-nodes. As the analysis continued, each category was developed to reflect the content of the data collected and draw out more detailed categories. In developing this process, the data was repeatedly analysed.

Table 1: Research Participants

	Role	Sector		Role	Sector
Participant 1	Project Manager	Commercial Developer	Participant 5	Sustainability Consultant	Independent Practitioner
Participant 2	Services Engineer	International Consultancy	Participant 6	Architect	Small Consultancy
Participant 3	Director of Surveying	Local Authority Consultancy	Participant 7	Senior Architect	National Consultancy
Participant 4	Sustainable Design Manager	National Contractor	Participant 8	Director of Development	Local Authority

EMERGENT VIEWS FROM PRACTICE

Sustainability Awareness

The majority of professionals interviewed portrayed a sufficient understanding of the theory of sustainability, when asked what they thought sustainability was and what it entailed the majority suggested that sustainability was *“the whole kind of environmental, social and economic stuff”* (Int.2) and *“sustainable construction involves more than just the building”* (Int.1). However, this understanding does not always translate into support for the concept, as one respondent espoused *“Whilst I understand sustainability, it’s not a philosophy of subscribe to in all honesty as I don’t think it is really proven”* (Int.8). Yet the majority routinely considered how sustainable construction could be enshrined into the projects they were involved with, although this was often constrained by their professional role. Nonetheless, a consensus of support emerged, together with an apparent desire to increase their knowledge and understanding of sustainability.

Despite this commitment, when asked about the specifics of their contribution the majority lacked the knowledge required to competently explain how they had implemented their principles in practice. Namely, that they sought to incorporate methods and techniques to mitigate against environmental impact. As one architect explained they had *“put on what would you call it . . . Eco bling I suppose, slap it all on the buildings, but it doesn’t serve a purpose”*(Int.6) whereas the services engineer explained he *“design[ed] sustainability systems [by] throwing in PV panels. Considering wind turbines, ground source heat pumps or whatever technology”*(Int.2).

Challenges of current practice

Given the discussion above it is perhaps not surprising the professionals interviewed identified a number of challenges associated with the implementation of sustainability.

Sustainable development driven by legislation

The majority of those interviewed for this study continue to view sustainability as a target driven concept associated with a need to tick boxes to ensure compliance with government policy, rather than something that can genuinely enhance the project, society and the environment. As one consultant candidly admitted *“If I am honest [we are implementing sustainability] not particularly out of choice but . . . because of legislation more than anything”* (Int.3).

Examples of this compliance culture included a 14-storey student accommodation building, where the architects suggested they in effect added a token sustainability feature to meet the planners' desire for sustainable buildings. Where the architect admitted, *“We put a green roof on it [the scheme] as planners want to see sustainable methods”* (Int.6). Unfortunately, this has on occasion led to a situation where various regulations and policy demands become contradictory, as there *“tends to be an overlap with planning, building regulations and other regulations. And you're finding that you've got a conflict sometimes between the two, or that you're doing things twice because the planners want it built to [a specific] BREEAM [standard]”* (Int.3).

With such a strong compliance culture, it is hardly surprising that professionals feel disconnected and even resentful of sustainability. Imposing sustainability on the construction industry in such a target driven way is damaging future evolution. With a number of professionals, admitting they feel so de-motivated and disinterested in sustainability, they do the minimum demanded. As one architect opined, *“there is very much an attitude of getting away with it i.e. what's the minimum we can do to achieve the minimum requirements”* (Int.7).

Dominance of sustainability assessment frameworks

Given the strong focus on BREEAM amongst regulators, it is perhaps unsurprising that the interviews revealed widespread support for the use of frameworks such as BREEAM. Predictably, the sustainability consultants argued BREEAM provides *“a good way for somebody saying or taking any design team to get them to do something better and make them reevaluate what they are designing. . . .in terms of sustainability”* (Int.4). A view strongly supported by a second sustainability consultant who argued the framework not only considers energy and carbon but also *“assesses the ecology of the site, recycling to help reduce waste and all that kind of stuff and also look at management issues”*(Int. 5). Whilst others felt the adoption of frameworks such as BREEAM bridged the gap between traditional and more sustainable ways of thinking about buildings. As an architect explained, *“it gets some options on the table and have a look at which one will suit you best”* (Int.6) without the need for an extensive understanding of sustainability, as one Project Manager attests, *“What we actually need to know to comply with BREEAM it's next to nothing to be honest”* (Int.1).

Others, however, were critical of the use of such a rigid points driven approach, reinforcing Rees (2009) assertion that the BREEAM is methodologically flawed. For example the director of one local authority consultancy argued that such frameworks are *“quite academic in outlook leading to a situation whereby a lot of effort goes into scoring a few points, which, sometimes, is not even adding anything to the sustainability of the building”* (Int.3). A view further espoused by the CEO of a small practice who suggested they would *“sometimes question the value in people's time in achieving those points for very little ... fine if it's going to increase the thermal efficiency of the building, those sort of things are great, but there are other elements*

where you begin to wonder is this really value for money in as much as how much it's costing to actually achieve it" (Int.6).

Client understanding

A number of the participants suggested a lack of both commitment and understanding on behalf of the client presented a fundamental barrier to sustainable construction. One sustainability consultant suggested, *"not every developer and client are as well informed or as well educated about sustainability" (Int.5)*. A view echoed by the services engineer, who opined *"you tend to find that the construction professionals have all got sustainability upmost in their mind but the clients haven't" (Int.2)*. Yet as a sustainability consultant suggested this situation was evolving, with public sector clients becoming *"switched on to sustainability [and] leading the private sector on that sort of thing" (Int.5)*. When asked why she felt this was the case, she suggested the public sector was simply more informed about the need to embrace sustainability, as *"not every client are as well informed or as well educated as others" (Int.5)*.

Yet those employed directly by client organisations portray a different picture of sustainability awareness. In the private sector, a project manager employed by a developer suggested the incorporation of sustainability was not reflective of the organisations' knowledge, understanding or awareness. It was a commercial decision, driven by the need to respond to market demand. *"It all depends on who the tenant is. Some tenants are very BREEAM driven. If you're a commercial developer and you've got a block of offices and you can offer 'BREEAM Very Good' or 'BREEAM Excellent' it's a big tick in somebody's corporate and social responsibility to move into the building" (Int.1)*. Whereas those in the public sector suggested sustainability was not optional *"if you want the funding for some project or other you need to prove how sustainability will be achieved it's as simple as that" (Int.8)*. Whilst client awareness presents a challenge, the majority of professionals suggested sustainability would only be incorporated when the market, legislation or government policy demanded it.

Establishing a suitable learning environment

The consultant interviewed alluded to a significant shift in attitudes towards sustainability, suggesting more of the professionals she worked with were showing an increasing interest in delivery sustainable buildings. However, despite this, she still felt the industry was not doing enough to facilitate sustainability literacy, as the *"lack of education in the industry means professionals lack the understanding they need to advise their clients" (Int.4)*. In an attempt to develop a better appreciation of the viability potential of formal and informal pathways to learning, views on learning opportunities ranging from self-directed study through to sustainability qualifications were elicited.

When questioned directly about enhancing their sustainability literacy, a number of respondents felt they only needed to know and understand enough about sustainability to successfully implement frameworks such as BREEAM and to ensure legislative requirements are achieved. One project manager opined, *"What we actually need to know to comply with BREEAM is next to nothing to be honest" (Int.1)*. Knowledge a sustainability director asserted could be acquired from legislation, as it is *"starting to come through and saying to a laymen reader that this is what we are expecting you to do in [this] aspect of sustainability" (Int.5)*. Yet the director of an architectural practice felt, *"a self-directed approach is fine if you're just working on projects requiring a relatively low level of sustainable design but you could not deal with a*

complex project this way” (Int.7). A view supported by another architect who warned “the literature is very confusing and you have to pick your way through it, so it's sometimes difficult to know that you're giving the best advice with so much confusing information out there” (Int.6).

The alternative to experiential learning is to undertake some manner of formal learning. Indeed the colleague of one participant “*is training to become a code assessor so there is someone within the office that can advise on green methods and techniques and point us in the right direction” (Int. 7) to enhance the ability of the practice to advise on and deliver sustainable design. Yet the sustainability consultant who completed a master's degree in environmental management warned of the dangers of attending short courses as those who complete them “don't always fully appreciate the complexities of sustainability and how it relates to the built environment” (Int.5).*

The alternative to attending short courses or CPD seminars is to undertake a structure programme of study offered by higher education providers. Although when discussing such intensive courses delivered by academics the project manager expressed concern that “*whilst they may well be provided a good commentary on sustainability, I think there's a fine line whether you go into too much detail and people switch off” (Int.1). A view echoed by the services engineer argued if such courses “talked about the building and how that impacts on sustainability and what you can do as a professional to impact on that or not impact on that, I suppose, that's where you would pick up and find it interesting” (Int.2).*

DISCUSSION

Sustainable construction has emerged as a clear agenda for the UK government, with a succession of top down policy documents published over the past decade calling for increasing levels of industry engagement with sustainability. Yet at the same time successive large-scale surveys of practice continued to reveal stubbornly low levels of engagement and understanding in terms of sustainability (Dale 2007; Dixon *et al* 2008; CIOB 2013; RIBA 2014) but seldom offered any deeper reflection from the participants as to why this occurred or indeed how their personal views and beliefs inform their practice. As with these earlier studies, the interviews revealed a significant disparity between construction professionals understanding and perception of the importance of sustainability and how these perceptions translate into practice.

The majority of practitioners interviewed demonstrated a clear commitment to sustainable development, with the majority suggesting all three aspects of sustainability were important to the construction process. Unfortunately however, with the majority engaged in trying to deliver sustainable construction from a position engrained in a business as usual model, the dominant paradigm in construction practice. This personal commitment to sustainability has not been translated into their individual practice. Indeed their slightly negative view of the sustainability agenda and a lack of literacy reflects the challenge they see in delivering an agenda that challenges business as usual with a more sustainable model which requires counter intuitive actions as market forces alone are unlikely to deliver sustainable outcomes (Rees 2009). As Rees (2009) himself argues, such actions require both top down legislative change as well as bottom up innovation. Whilst the former is evidence in the succession of government policy pronouncements, those interviewed didn't display the required level of sustainability literacy needed to instigate such bottom up approaches.

Whilst Murray and Cotgrove's (2007) on-going work with new entrants to the industry evidences that it is possible to provide a basic level of awareness, which can then be refined and extended through experiential learning in the workplace (Schweber 2013) to engender bottom up innovation. The interviewees were highly critical of this approach when used with mid-career professionals. Indeed many felt facilitating learning through targeted CPD or training was ineffective, with the majority favouring practice orientated experiential learning. However, throughout the course of the interviews the respondents sought to identify a number of barriers to the implementation of sustainable development which they used to try to justify why they could not engender further change in their practice, which calls into question the veracity of the arguments offered against formal learning processes given the support for such methods reported amongst other groups such as construction SME's (Gleeson and Thomson, 2012).

Despite, this however, a number of professionals suggested that they were beginning to embrace sustainability, albeit through the medium of assessment frameworks, a finding supported by Dixon *et al*'s (2008) study which found that the implementation of BREEAM was in most cases, the respondents only engagement with sustainability. Whilst such frameworks are in themselves open to critique, with authors such as Brandon and Lombardi (2011) questioning their appropriateness as they fail to appraise sustainability in its fullest sense. The interviewees felt such tools provided scaffolding around which experiential learning can take place, as they felt empowered to think about sustainability in an experiential way, with the safety net of expert guidance, a view reinforced by Schweber (2013). Whilst tools such as BREEAM represent little more than an adjustment at the margin that will in itself will not engender change (Rees 2009). Such adjustments can in themselves have a significant effect on the sustainability literacy of the professionals involved whilst moving the industry to a less unsustainable position (Rees, 2009)

CONCLUSIONS

The findings from this research raise questions about the sector's continued reluctance to engage with sustainability and sustainable development. The research findings suggest that the virtuous circle of blame observed over a decade ago has yet to be broken. With the professionals interviewed for this study engaged in trying to deliver an agenda from a position that is engrained in a business as usual model. Their slightly negative view of the sustainability agenda and a lack of literacy reflect the challenge they see in delivering an agenda that challenges business as usual with a more sustainable model that requires counter intuitive actions. Profit, client led decision-making and a regulatory system which remains slow and unwilling to challenge the industry to evolve its practices (evidenced by the code for sustainable homes abandonment in March 2015). This presents a system that is not going to achieve the progress required. Yet, those interviewed also didn't display the required level of sustainability literacy which raises the question, could a very different outlook have been achieved with professionals engrained in the sustainability agenda? In an attempt to advance knowledge in this area, further work is now proposed to test this hypothesis, the study will both expand the initial sample of professionals reflecting the dominant mode of delivery and contrasts this with a second series of interviews undertaken with professionals engaged in or desiring a more sustainable model of delivery. The 1st provides validation of our initial findings and the 2nd allows us to hear from those engaged in trying to deliver the agenda in practice.

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HARNESSING THE MOTIVATIONS OF ARCHITECTURAL DESIGNERS TO ENGAGE WITH SUSTAINABLE CONSTRUCTION

Niamh Murtagh¹, Aeli Roberts and Richard Hind

The Bartlett School of Construction and Project Management, UCL, UK

Engagement with the sustainability agenda is not only organisational but also personal. However, there has been little attention paid in the construction literature to psychological factors which can influence sustainable construction. Drawing on psychological theories of motivation, the current study aimed to address this gap. Owner-managers of 16 small architectural design practices in the London area were interviewed and inductive thematic analysis was conducted on their responses. Four clusters of themes emerged: excellence in design, self-identity, enjoyment and other job motivations, which included impact on people. These intrinsic motivations are likely to be pursued for their own sake but also align strongly with sustainability objectives. By associating sustainability goals with intrinsic motivations, sustainability discourses come to be not only about climate change or the environment but more fundamentally a part of what people want to do each day. In this way, the reach of sustainable design may be extended beyond those who have a personal interest and commitment to the environment, and may contribute to industry-wide change.

Keywords: architectural design, motivation, sustainability.

INTRODUCTION

The evidence for climate change is now unequivocal (IPCC 2014). Recent IPCC reports make clear the importance of construction and the built environment to climate change, and the potential to contribute to mitigation. Buildings consume around one third of global energy, and generate about the same proportion of black carbon emissions (i.e. carbon in particulate form) (ibid). Trends including population growth, urban migration and provision of adequate housing in developing countries may contribute to two- to three-fold increases of energy use and emissions by mid-century (ibid.). However, buildings also offer the greatest low-cost potential to reduce carbon emissions of any sector (IPCC 2007). The construction industry therefore has crucial responsibility to realise major improvements in the built environment.

Looking for ways in which to increase engagement of the industry with sustainable construction, the current study examined intrinsic motivations of architectural designers in very small practices. To explain our focus, we begin by reviewing the importance of small businesses in construction and specify how sustainability was defined in this study. The literature on SMEs and sustainability is then briefly reviewed, in particular the evidence for the significance of individual, psychological attributes of owner-managers of small businesses. The psychology literature is drawn

¹ n.murtagh@ucl.ac.uk

upon to differentiate between attitudes, values and motivations and the theoretical framework of self-determination theory (Ryan and Deci 2000) is outlined.

Research on sustainability in construction has burgeoned over the last two decades (Hill and Bowen, 1997, Kibert, 2007, Clarke *et al.*, 2008, Davies and Oreszczyn, 2012). Such research has tended to concentrate on large organisations. This focus is understandable due to the impact of major projects, their scale, complexity and cost. However, SMEs (small-to-medium enterprises) comprise the majority of the industry. SMEs are defined by the EU as businesses with fewer than 250 employees and turnover of under €50M, with micro enterprises defined as those with fewer than 10 employees (EU 2013). SMEs deliver 72% of turnover and employ 85% of workers in construction in the UK (BIS 2013). The significant improvement in sustainability of the built environment that the industry must deliver therefore depends critically on the engagement and action of SMEs (Hillary, 2000, Tilley, 2000).

Defining the term ‘sustainability’ can be problematic (Johnston *et al.*, 2007, White, 2013). Kibert’s (1994) definition of ‘sustainable construction’, as the creation of healthy, resource-efficient buildings designed from ecological principles, is usefully both succinct and broad-ranging. Nevertheless, within construction, different roles have different understandings of sustainability and different scope to influence sustainable outcomes. For example, the sustainability features which a planner could seek may vary greatly from those pursued by a services engineer. In order to focus the current research, we targeted SME architectural designers. For this study, we defined sustainable construction as encompassing the environmental impacts of construction, particularly the consumption of energy and the generation of carbon emissions and of waste, in the building process and in the operational use of the built product.

Existing research on SMEs and sustainability has looked at ‘barriers’ and ‘drivers’. Barriers that have been described include lack of resources, especially time, lack of knowledge and training (Smith *et al.*, 2000), absence of customer demand, absence of legislation (Gerstenfeld and Roberts, 2000, Hillary, 2004) and assumption of increased costs (Simpson *et al.*, 2004). Drivers include legislation, competitiveness, customer demand and interest groups (Gerstenfeld and Roberts, 2000, Hillary, 2000, Tan *et al.*, 2011). Argument has been made for the need to pressure SMEs into greater action on sustainability, via regulation and market forces (Bianchi and Noci, 1998). In the few studies with SMEs in construction, the role of the client in driving sustainability was emphasised (Revell and Blackburn, 2005, Revell, 2007). These drivers (regulation, market demand) have been considered as external influences, but a number of studies have suggested that factors within the organisation may be more important (Gerstenfeld and Roberts, 2000, Quinn, 1997). Internal drivers have included cost reduction and new market opportunities (Van Hemel and Cramer, 2002) but beyond these business drivers, factors which relate to people have been discussed, such as environmental concern (Van Hemel and Cramer, 2002), values and attitudes of owner-managers (Perez-Sanchez *et al.*, 2003, Tzschentke *et al.*, 2008, Hillary, 2000) and personal motivation (Petts, 2000). We would argue that the recognition and examination of personal motivations are an essential component in understanding how small businesses operate. As Roxas and Coetzer (2012: 463) note: “*beliefs, values, attitudes and strategic mental models of the owner-managers ultimately determine the strategic direction, configurations and practices of the firm*”. However, owner-manager attitudes towards sustainability do not necessarily translate into action (Cassells and Lewis, 2011). There is thus a need to investigate not only motivations

around sustainability but motivations more generally, to examine how they may advance sustainability in construction.

Studies which have considered attitudes, values and motivations in SMEs have tended to confound these concepts but attitudes, values and motivation are understood as different constructs in the psychology literature. While attitudes are based on beliefs, values are defined as part of self-identity (Gatersleben *et al.*, 2012). In contrast, motivation may be defined as how behaviour is triggered, energised, sustained and directed (Wiener, 1992). Theoretical understanding of motivation links it closely with conation, or intention. Traditionally, three facets of mind have been studied within the discipline of psychology: cognition (what people think), affect (how people feel) and conation (why people choose to act as they do). The conative perspective of motivation sees the individual as “*intentional, planful, deliberate, goal-oriented...proactive*” (Huitt and Cain, 2005: 1) and it is this perspective which informed the current study. We wanted to explore what drives people in their work, and specifically owner-managers of micro-business in architectural design, to identify whether their motivations could align with sustainability goals. People in organisations are multiply-motivated and pursue many goals simultaneously (Babiak and Trendafilova, 2011) and therefore we examined their motivations in general, not only those around sustainability and the environment.

Self-determination theory (SDT; Ryan and Deci, 2000) provided an apposite theoretical framework. SDT conceptualises the person as possessing fundamental needs for autonomy and competence, and was therefore particularly relevant for examining the motivations of business owner-managers. The individual is conceived to be innately driven to learn and grow. These innate drives can motivate behaviour although motivated behaviour can be enabled or thwarted by context. Forms of motivation range along a spectrum from extrinsic to intrinsic. Context can offer extrinsic inducements such as customer demand, increased market share or fear of regulatory non-compliance. With extrinsic motivators, others wield control. While such motivators can be effective, their effect tends to be limited and motivated behaviour is maintained only while they remain in force. In contrast, behaviour motivated intrinsically tends to persist longer and to be more resilient in the face of obstacles. Such intrinsic motivations are triggered by psychological factors within the person, such as identity (who the person perceives him/herself to be) and values (what is important to the person). The literature on SMEs and sustainability has tended to focus almost exclusively on extrinsic motivators, such as market demand and regulation. We wanted to address the gap on intrinsic motivations of SME owner-manager.

In sum then, people in general – and we may suggest SME owner-managers in particular - tend to be self-directed and intentional. They are multiply motivated and their motivations will be extrinsic and intrinsic. With respect to sustainability, it is likely that intrinsic motivations are more likely to drive persistent behaviour. This theoretical framing informed the research questions for our study: How do their individual motivations influence sustainable design by architects in micro-practices, and what scope is there for harnessing their intrinsic motivations to increase engagement with sustainability objectives?

METHOD

To address the research question in depth, we chose the qualitative method of semi-structured interviews and inductive thematic analysis. The interviews were conducted

in conjunction with a project delivering basic eco-design training. The interview schedule permitted wide-ranging discussion on delivering sustainable construction while the explanation of eco-design provided a focus to ensure commonality of understanding of sustainability in construction. The owner-managers of 16 micro-businesses were interviewed, in conjunction with the employees where possible. Of the 16, 11 had one or two employees and five had between 5 and 9 employees. The businesses were all based in the Greater London area and offered architectural design services (13), structural engineering services (2) and landscape design (1). Projects ranged from hundreds of pounds to £3million, with a 'typical' project size of under £100,000. The majority of work was in the domestic sector, primarily extensions and refurbishments as well as new build. The interviews, including training sessions, lasted between one and two hours and were audio-recorded and transcribed verbatim. Qualitative analysis software, NVivo V10, was used to aid analysis.

FINDINGS

In the extracts given, the business is indicated by Bn and individual speakers by Sn.

Excellence in design

A common theme in the responses was that of excellence in design. Participants spoke of seeking to do their best to meet the client's brief: "...we appreciate that, for the small private client, the thing we do impacts them for a long time, so it's best to do it as best as you can" [B15], and designing "better than just doing it how we could do it" [B9]. In many cases, they sought to go beyond what the client had requested, using their knowledge and creativity to offer more:

"Quite often, what I've done in the past, depending on the size of the project, is take the client's brief, do something fully compliant if you like and then turn it on its head and offer them something else and more often than not they might be interested in the something else" [B5].

A couple of participants contrasted their high standards for work they now do with work they had done before: "My new model is that I will do a very nice job...I've done too much mediocre work during the recession. I'm not prepared to do it anymore...It's got to be high quality work" [B10]. The strength of this as a motivator for some was clear in the following extract:

"Sometimes you go to work and you think you're actually going to do something that someone is going to be really really pleased with and when that turns out, that's the positive thing, that's what keeps it all going" [B5].

In a number of accounts, sustainable design appeared to align with excellence in design. The architects described sustainable design as "designing responsibly" [B9] and using "proper architectural principles" [B16]. As one participant summarised it, "the issue is about the quality of the design, rather than the end result of its U value" [B15]. Thus the participants pursued high quality in their designs, and some recognised ways in which designing for sustainability was part of pursuing design excellence.

Self-identity

In many ways, the architects' motivations appeared closely linked to self-identity, that is, who they saw themselves as being. A professional identity was in evidence, for example, B2 said, "I couldn't really imagine myself doing something different", and

several participants referred to themselves and other architects as professionals. There was a clear sense of ownership of their designs:

“I remember when I used to work out on site and at the end of the day I could walk off and say ‘do you know what, I built that today’ ... and it’s really rewarding” [B4]

In describing his motivation, another participant said *“I own all this and I get to finish it”* [B5]. One participant mentioned the *“ego and vanity”* of some of his earlier designs [B10] and another recognised the extent to which she identified with her design work: *“When you’re designing something, you don’t think of someone pulling it down, because that would hurt, wouldn’t it?”* [B3]. This point on the relationship between their self-identity and their designs was made clear in a reflection by B16:

“I think there’s a tendency in architecture, ‘cause the nature of architects being who we are, we like things to have an enormous legacy.”

In this extract, the speaker refers to identity as part of a profession or a group of people (*“who we are”*) and the extent to which the work of architects, the end-product of design and building, helps to construct that identity.

Some participants linked their interest in sustainable design explicitly to their self-identity, speaking about being *“passionate about recycling at home...Because I as a person am environmentally conscious, well try to be, you know and if I can do something then I will”* [B4] and the pervasiveness of their thinking about sustainability: *“It is always in the back of my mind because I am personally interested in the environment generally”* [B3].

So there was close alignment between their designs and their sense of self for the participant architects, and for some, their interest in sustainability was a further aspect of self-identity expressed in their work.

Enjoyment

In addition to pursuing excellence in design and self-identity, the architects’ motivations in their work also centred on enjoyment. Several spoke of enjoying what they do: *“I think we’re fortunate insofar as we do enjoy what we do... I love coming to work in the morning.”* [B4]. Specifically for some, it was the creative process which they particularly enjoyed: *“I think we’re quite lucky with the skills that we’ve got, that we get up in the morning and we can come in and we can do something creative.”* [B9]. For others, it was the tangible nature of the outcome that carried the most positive emotions:

S1: Creating something tangible.

S2: Driving around and saying ‘I did that’...

S1: For me the tangibility of it is massive. [B4]

Thus the participants gained satisfaction and enjoyment from the creative and tangible aspects of their work.

Other motivations

Beyond excellence in design, self-identity and enjoyment, other motivations emerged. A few participants mentioned pay, although all also described other motivations alongside pay, for example, *“[Paying] the bill’s second place but this is what I always wanted to do so that is the first place”* [B4].

A perhaps less expected motivation was the impact of their work on other people:

“You’re making such a huge choice and influence... It basically shapes everything we do. And then we’re just making really quick decisions that will affect people for a vast majority of their life.” [B1]

This acknowledgement of influence on the lives of their clients, continuing well into the future, was evident in a number of the accounts. For example, B3 described how her work helped people: *“Sometimes I go and see a client and ... I think they’re thinking ‘oh my God why did I buy this house’, and you can actually make it work for them...”*. Describing a specific current project, B10 said *“I’m very aware that they’re putting everything into it. We have to borrow some money”*. He begins this extract by talking about the clients (*“they”*) but moves on to acknowledge the joint nature of the project (*“we”*), clearly putting himself into his client’s shoes. One architect, who worked primarily on old buildings, spoke of her love for heritage architecture as a motivation: *“I love old buildings and I always loved you know that idea of new life in old buildings and reusing buildings” [B3]*.

As described above, the participants had volunteered for training on eco-design, so in the analysis we looked for indications of motivations specifically around sustainable design. Several architects noted the ethical dimension and even a moral imperative: *“It’s wrong to do nothing. You’ve got to do something and you’ve got to think about what you’re doing” [B5]*. It appeared that some participants had gradually realised their own role and responsibility:

“It’s only in the last couple of years that I’ve really started to think, ‘Actually got to start doing something about this,’ rather than carrying on writing out Celotex on my drawings, you know, actually do something” [B11].

A final factor which appeared to influence motivations for sustainability was that of positive and negative attitudes. Of the 16 participating practices, only one expressed several negative beliefs about sustainable construction, including concerns over perceived difficulty and lack of knowledge, assumption of increased cost and reduced availability for sustainable materials. Other participants raised concerns that clients will always seek the cheapest option and choose minimal compliance with legislation. Negative attitudes such as these could be seen to frustrate motivation towards sustainable design. However, other architects took a positive view and the following extract is an example of a robustly positive approach:

“It’s a very similar strategy that we have [with sustainability as] with actually planning which is we’re always pushing the boundaries, because if you sit and say, ‘Well we’re just going to have that little box.’ Yeah, you know you’re going to get that, that’s fine...but if you start going bigger and taller then you might not get all of that but you’re going to get a hell of a lot more than if you just accepted the little box. So I think it’s a very similar sort of process and thinking.” [B9]

This speaker saw similarities between sustainability in design and other design aims. Her practice routinely dealt with constraints – planning constraints are mentioned in the extract – but took the view that attempting to ‘push the boundaries’ resulted in greater success. Her positive approach would seem to facilitate motivation towards sustainability. Thus, although attitudes and motivation are separate constructs, they are connected, with attitudes providing a context, positive or negative, which influence how motivations take shape and are played out.

DISCUSSION

The literature on sustainable construction points to the potentially considerable impact of personal motivations. We interviewed 16 owner-managers of micro enterprises offering architectural design services. Amongst the motivations for their work were: pursuit of excellence in design, self-identity, enjoyment and impact on people. These linked to sustainable design for some participants, and there were additional motivations around sustainability, specifically the ethical or moral imperative.

Some of the participants had understood the ethical dimension of sustainability and a few had described their moral motivation to pursue sustainable construction. This can be understood as an activated personal norm or moral obligation, which has been shown to contribute to pro-environmental behaviour (Stern *et al.*, 1999). This speaks to professional as well as personal pride: these participants had realised their influential role and in fact their responsibility to try to make changes. The importance of the personal conviction of the architect-director has been noted previously (Blau, 1984), as has the moral responsibility of designers and the potential for designers to become agents of change (Farmer and Guy, 2010).

A point worth noting was the influence of attitudes on motivation. For one enterprise, a generally negative conception of sustainability appeared to make it unlikely that improvement would be pursued. In contrast, a few participants showed a robustly positive approach, through which they felt that they could achieve change. Extensive early research on attitudes has determined that, contrary to expectations, attitudes and behaviour correlate relatively weakly (Wicker, 1971) and other factors, including a sense of self-efficacy (Armitage and Conner, 2001), strengthen the predictive value of attitudes. This would suggest that more widespread knowledge about sustainable construction, by contributing to a sense of competence in the domain, could help to increase green design.

Beyond motivations that appeared directly to drive sustainable behaviour were other intrinsic motivations which, we argue, may be linked indirectly. The pursuit of excellence is perhaps not surprising for a professional group, particularly a set of individuals who were managing successful businesses. Although excellence of product lends itself to commercial value, here the focus was specifically on design rather than excellence as a marketing strategy. A number of respondents linked sustainable design to high quality and this suggests one way in which sustainability may gain wider appeal amongst designers. The participants provided interesting indications of the extent to which their self-identity, and that of architects in general, was bound up in their designs. These factors had been noted by Caven and Diop (2012) in their study of architects. They too found robust examples of the importance of the profession to self-identity and of creativity and they found these to be intrinsic rewards in the profession of architecture. Self-determination theory (Ryan and Deci, 2000) offers further insights into how such factors may contribute to motivation. The creativity of the design process is likely to be 'intrinsically motivating', that is, enjoyable in and of itself. Behaviour which supports or enacts an aspect of identity is also highly motivating. Norms such as ethical behaviour which have become internalised are also strong motivators. Thus creativity, professional identity and ethical concerns may all be considered as intrinsically motivating. As such, they are likely to drive behaviour that does not require additional external incentives and is likely to persist in the face of obstacles.

The study presented here involved only 16 architectural practices and statistical generalisability is not claimed. Nevertheless, theoretical understanding of human motivation suggests the potential for some of the findings to apply more generally in construction, beyond architects in micro enterprises. While the focus on design and creativity may be particular to designers, motivations around the pursuit of excellence, self-identity including pride in legacy, and impact on people, may be widespread amongst other construction professionals. Future research could usefully examine the motivations of other construction professionals to establish whether these or other motivations offer potential 'hooks' for sustainability.

CONCLUSIONS

Associations may be drawn between the intrinsic motivations in evidence in our participants' responses and goals of sustainable design. The participants spoke of ownership, of vanity and ego and of the general desire of architects to leave a lasting legacy. Sustainability goals of durability, designing for re-use and extended life for buildings aligns closely with desires for legacy thus achieves the aims of both.

With respect to client satisfaction, design for operational energy efficiency and application of passive design principles can be linked to greater comfort, efficiency and overall value to the client. The motivation of the participants to consider impact on people as fundamental to their design aligns with sustainability goals of a built environment which contributes to human well-being.

We argue therefore that there is considerable scope to connect sustainability goals with the wider motivations of architectural designers. The focus in this study has been on positive motivation for sustainability and positive motivations in work more generally but this is not to suggest that all businesses are motivated to become more environmentally sustainable. Indeed, attitudes from the study participants were not uniformly positive. In the population at large, attitudes to environment matters can vary considerably (Pidgeon, 2012). By associating sustainability goals with intrinsic motivations, discourses come to be not only about climate change or the environment but more fundamentally a part of what people want to do each day. In this way, the reach of sustainable design may be extended beyond those who have a personal interest and commitment.

Linking sustainability and intrinsic motivations is not automatic. Moral norms require activation in context to influence behaviour (Stern *et al.*, 1999). Extrinsic motivations such as financial inducements can undermine intrinsic motivation (Ryan and Deci, 2000). Professional identity is developed through socialisation (Imrie and Street, 2014), both during education and within organisations. There is a need therefore to enhance curricula to embed sustainability goals more broadly in the everyday practice of design, and to develop more extensive discourses in organisations around impact on people. Designing for sustainability could increasingly become business-as-usual, meeting a diversity of motivations, rather than an often-contested, environment-specific 'add-on'.

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MANAGING SUSTAINABILITY THROUGH DECISION PROCESSES: THE INFLUENCE OF VALUES AND FRAMES

Richard Kulczak¹, Poorang A.E. Piroozfar and Marie K. Harder

School of Environment and Technology, University of Brighton, BN2 4GJ, UK

Delivering projects to minimum requirements in the UK construction industry can come at the expense of longer-term sustainability goals and unseen impacts. Without measurement, such trade-offs often remain unaccounted for. Therefore, managing sustainability becomes a significant challenge, with subsequent downgrading to a 'box-ticking' exercise—itself a process-orientated procedure with little attention to broader project impacts or end conditions. A more direct and holistic approach to understanding and later influencing sustainability in design decision making is to research the values and problem framing which occurs in early practitioner-client interactions. By reinterpreting underlying processes in human decision-making for architectural sustainability, key themes and sub-processes can be transparently examined, thus facilitating their engagement and enabling. Early findings suggest that reciprocal influences of human values and decision-problem framing play a fundamental role in shaping sustainability decision processes. Explicitly and implicitly, practitioners appear to gather and evaluate interpersonal and values-orientated information, on which they base assessments of a client, their position on sustainability, and its flexibility. Such intuitive analyses provide practitioners with beneficial psychosocial heuristics to approach and advance sustainability issues. These 'indicators' provided guidance on using situation-appropriate communication frames to achieve particular results. Thus, values engagements and influences, on and in conjunction with problem-frames, structure and guide sustainable design decision processes. Values and communication frames appear reciprocally influenced and self-reinforced, amounting to structural psychosocial drivers, or barriers, of sustainability.

Keywords: decision-making, human values, stakeholder engagement, sustainability management.

INTRODUCTION

Sustainability in the UK construction industry is well received; building designers and construction professionals are understood to be well-versed in practical processes and technological solutions. However, many projects only deliver minimum requirements, frequently at the expense of longer-term sustainability goals and unseen impacts (Williams and Dair 2007, Dowson *et al.* 2012). Currently, these trade-offs are not specifically accounted for because they either cannot be measured or there is little willingness to measure them. Sunk costs and indirect impacts are notoriously challenging to disaggregate, and cost versus value trade-offs are established problems (Mills 2013). This scope of trade-offs is not currently measured in sustainable building assessment systems, nor are they effectively addressed in regulations in a broad, holistic context commensurate with c21st thinking (Moe 2007).

¹ r.kulczak@brighton.ac.uk

Managing sustainability therefore has become a significant challenge, leading to its subsequent downgrading to a 'box-ticking' exercise in which points are given to seemingly useful measures and assessed as a process-orientated procedure with little attention to broader project impacts or end conditions. This work focuses on the missed opportunity to obtain a measure of the degree of sustainability of a project at a very different stage of the process—the initial practitioner-client interaction stages. It is in these early stages that the future agreed project is framed, with that framing being formed by contributions from both parties. Decision-making later follows broadly from that framing and may become less susceptible to significant change if based on stronger foundations. The human interactions occurring in this early, critical phase might be shown to be crucial to subsequent pathways and outcomes, which are examined in detail via in-depth interviews at the individual level. These fundamental human interactions and influences are almost entirely overlooked in sustainable design decision-making, particularly the initial interpersonal exchanges that set the character of and outlook for sustainability. Yet research in sustainability science and environmental sustainability suggest that values and frames are key fulcra in human psychosocial processes involved in bigger-than-self issues, including the long-term and unseen impacts from building design (Arvai *et al* 2012, Darnton 2008, Crompton 2010, Chilton *et al.* 2012).

The two questions addressed in this research are closely interlinked. What influences in early sustainable design decision processes are the result of human interactions? What are the influences of human values and problem framing in sustainable design decision processes? The aim of this research therefore is to investigate missing links in human psychosocial dimensions of sustainable design decision processes. Here, advances can be made to promote the sustainability agenda at an early and fundamental stage of the procurement process. These links are missing because they have been investigated insufficiently and are not leveraged in current practice.

The objective of the first phase of this three-phased research project investigates the variables influencing sustainable design decision processes at an individual level, by interviewing practitioners in-depth about their early practitioner-client interactions regarding sustainability. This paper reports on the initial findings of the first phase interviews. Phases 2-3 later will involve further interviews, focus-group workshops, and surveys with different companies to examine first interpersonal and then group-based influences of values on decision problem framing. This approach is intended to expand the sustainability debate by recognising the dynamic, complex, and multiple human variables implicit in everyday sustainable design decision processes. If found in Phase 1, the following phases will connect construction and design management research to literatures in values and framing for sustainability.

This is important because examining the human, psychosocial processes and influences in sustainability provide a new approach to sustainability, placing the individual in the context of the social; the obvious immediate in the context of unseen consequences and impacts; and smaller decisions in the context of larger impacts. This kind of approach is alluded to by authors advocating innovation and broader thinking for sustainability (see e.g. Moe 2007, Hoffman and Henn 2008, Brand 2004).

LITERATURE REVIEW

Increasingly since 2000, researchers have recognised the importance of incorporating social dimensions in generating solutions to sustainability issues in architecture (Brand 2004, Guy and Moore 2004, Cole 2000, Guy and Shove 2000). This has

occurred alongside recognition of the influence and importance of underlying inter- and intra-personal drivers and barriers arising from human values, beliefs and norms; motivations, opportunities and abilities; and other characterisations (Darnton 2008, Guy 2006, Henry and Dietz 2012, Schweber and Leiringer 2012). Intricate, compound, scale- and time-varying ecological, social, political, and economic conditions influence human sustainability, whereby the “*processes of decision-making directly affect the sustainability of their outcomes*” (Adger and Jordan 2009: 6). Therefore, more holistic approaches to decision-making, and setting the stage with better problem-framing, can begin to address multi-scalar and complex influences on sustainability decision-making (Haughton and McGranahan 2006). Holistic approaches to decision-making in design for sustainability that combine ‘small everyday’ with ‘large planned’ strategic decisions can consciously, and unconsciously, shape the broader impacts of architecture and urban sustainability (Haughton and McGranahan 2006). Moreover, the scale and domain in decision planning is a critical dimension to recognising the full scope of built environment influence and impact (du Plessis 2011, du Plessis and Cole 2011, Guy and Marvin 2001, Brand 2004, Kibert *et al.* 2006). This is particularly relevant because certain processes in sustainability “*can be more readily observed at some scales than others*” and impacts can be simultaneously direct and indirect (Alcamo *et al.* 2003).

Decision-making is a complex cognitive process influenced by a variety of interacting factors from multiple sources frequently beyond conscious awareness. Facts, evidence, and information only play partial roles in decision-making practices, where human emotions, beliefs, and values present significant influences at both individual and cultural levels (e.g. Arvai *et al.* 2012, Chilton *et al.* 2012, Crompton 2010, 2013, Darnton 2008). Socio-cultural norms, shared values, individual beliefs, attitudes, values, and emotions are all very closely linked and influence decision processes (Crompton 2010, Darnton 2008, Stern 2000, Dietz *et al.* 1998).

Considerable research suggests that values and frames are key leverage points in human psychosocial processes involved in bigger-than-self issues, such as the long-term and unseen impacts in building design (e.g. Arvai *et al.* 2012, Darnton 2008, Crompton 2010, Chilton *et al.* 2012). This potentially avoids making easily-overturned gains achieved through financial incentives or selective provision of information (Kollmuss and Agyeman 2002). Recent research has shown how the recognition of human values is emerging in ‘soft’ project management for construction sustainability that seeks new routes for value creation through better engagement with people in holistic, open, and meaningful ways (Mills 2013, Novak 2013, Thomson *et al.* 2003).

Values are fundamental, underlying drivers of motivations and behaviour, signifying what is important to people (Schwartz 2009). As Cheng and Fleischmann (2010: 1) summarise, “*values are a unique psychological construct that are prominent antecedents to decision-making and behaviour at the individual and societal levels of analysis.*” Values are important to managing sustainability based on three principal facets; they are: an identifiable variable in psychosocial processes; measureable; have shared meanings across cultures (c.f. Stern *et al.* 1998, Dietz *et al.* 1998, Oreg and Katz-Gerro 2006, Schwartz 2011, Harder *et al.* 2014, Hoover and Harder 2015, etc.).

In addition, values are also closely connected with how people make sense of the world: “*...one way this connection manifests itself is through frames. Frames in general are both mental structures that order our ideas; and communicative tools that*

evoked these structures and shape our perceptions and interpretations over time (Holmes et al. 2011: 36).” Various levels of ‘framed ideas’ or ‘framing contexts’ include snap-shots, broader perspectives, and entire mind-sets. Value judgements, as assessments of value or worth, can be considered a type frame encircling what is and is not important, thereby reflecting the values of the ‘framer.’ As Myers (2010: 12) asserts, “*the label [or frame] reflects the judgment.*”

Framing in decision-making is a heuristic or interpretative mechanism that provides a mental representation of the decision-problem that identifies the available options for an issue under consideration (Beresford and Sloper 2008, among others). Problem-framing is a key factor in decision processes, arising as a resultant sub-set of values and broader frames in a reciprocal and mutually influential relationship (Robbins et al. 2008, Holmes et al. 2011). The way in which options are framed, as well as the order they are presented, have significant impacts on the outcomes of decisions, which can also produce results opposite of intentions (Darnton 2008, Jones et al. 2012). Beamish and Biggart (2010: 2) discovered that “*social heuristics—collectively constructed and maintained interpretive decision making frames—influence economic decision making practices and material outcomes,*” having led to at least one case of failed innovation in large-scale commercial construction. Together, values and frames can be employed in sustainability “*...toward systemic change that is less susceptible to variations in behaviour and ultimately reinforcing the more consistent, underlying principles or standards from which our behaviour derives*” (Holmes et al. 2011).

The literature above indicates that values and problem framing are crucial factors for structuring decision making processes, yet they have not been explicitly studied in design management interactions; the work described here examines that area.

RESEARCH DESIGN AND METHODOLOGY

The Phase 1 research has been designed, planned, and iteratively fine-tuned based on emerging results and findings from field research and literature in constant comparison. It takes a case-based grounded approach, involving key individuals and groups of decision-makers from building design companies and client bodies. The domain of study is the interpersonal practices of individuals in groups of two or more, seen from the perspective of building designers, and how those individuals communicate, interact, and influence sustainable design decisions. A case-based approach allows for each organisation (‘horizontally’) and project (‘vertically’) to be naturally identified as a case or ‘category of analysis’ (Yin 2009: 12).

Utilising a grounded analytical approach provided the opportunity to collect and analyse the data based on rigorous, linked recording, and examination methods capable of providing records of developments, or ‘chains of evidence’ also used in case study methods (Yin 2009: 41). By constantly comparing collected data against literature, against conceptual and theoretical understandings, this approach allowed building up an increasingly broad perspective towards explanations grounded in findings yet related to literature. Through coding and categorising the data according to concepts and themes as appropriate descriptions for the apprehended phenomena, the data was coded and assembled directly from the different groupings of participants and their experiences as expressed in their responses (Strauss and Corbin 1994, Creswell 2003). As Charmaz (2011: 501) asserts, “*data collection and analysis reciprocally inform and shape each other through an emergent iterative process.*”

DATA COLLECTION AND ANALYSIS

For the Phase 1 interview process, participants have been chosen based on having a minimum of 10 years professional practice experience with sustainability issues in building design were initially identified in accordance with a set of detailed procedures—ten were invited through the lead authors' professional network. This was based first on length of experience in years, second on experience in varied sectors, third on availability and accessibility in a relatively short timeframe. With an anticipated recruitment response rate at 50% (Baruch and Holtom, 2008), it was felt that a 60% response for the first of three phases was acceptable. Four architects, one technologist, and one design engineer were interviewed from four different organisations. A series of open-ended questions were based on the five-part objective and selected by their ability to capture key underlying processes in approaching, engaging, framing, delivering, and 'futuring' sustainability. This was bounded in such a way as to capture key exchanges, conditions, and constructs at the spaces where people interact with and influence sustainability in decision processes. The interviews discussed issues about engaging key stakeholders in decision processes for sustainable design, including such matters as raising sustainability topics, committing to sustainable solutions, making or accepting changes affecting project sustainability.

First, interview transcripts were broadly reviewed, then closely analysed, and distilled into a series of statements and highlights of key points, prevailing threads, and observations. Then transcripts were 'open' coded and categorised with an 'open frame' in constant comparison between coding, memos, and transcripts, in which phenomena arising were classified purely by their content and meaning rather than assigned any predetermined concepts. Thus, analysis naturally extracted codes that were bounded by the questions themselves, thereby inherently limiting the range of codes arising. These were rationalised and refined into several explanatory codes and then categorised according to predominant topics that arose. Responses naturally fell into six categories: engagement, approach, drivers/influences, actions, framing, values, (participant) observations. All analyses were cross-referenced into an analysis matrix for crosschecking. To identify specific influences of values and frames, the transcripts and analysis matrix were re-examined with a 'values lens' and a 'frames lens' to draw out relationships and influences from these perspectives (Harder *et al.* 2014). These were separately re-coded into frames used by practitioners to represent sustainability, and 'value statements', giving rise to several subcategories of values and framing. Codes and categories were re-compared with corresponding texts for consistency.

Results identify not only that values and problem-framing influence decision processes, but also that these influences vary in scope and magnitude depending on the value a practitioner places on sustainability, and the practice environment, in relation to other relevant factors. These include practitioner and practice value-systems, individual(s) with whom they interact, the project itself, and relevant conditions of the prevailing environment, whether implicit or explicit. The way practitioners progress sustainability appears to be closely associated with their 'value-system', influenced by their experience, company 'focus' and value-system. Reflection on these interviews, in constant comparison with the literature, has revealed a structure of key design decision processes and influences.

From the interviews, it appears unanimous that decisions about 'levels of sustainability' are raised by practitioners with their clients almost from 'day one' because of their complexity and cost implications, necessitating early commitment. Practitioners engaged stakeholders with sustainability issues 'where they are at'—they

endeavour to discover what their clients are ‘like’ and are ‘willing to accept’ in terms of functionality, aesthetics, and sustainability. As one practitioner advised: *“when I’m first meeting [a stakeholder], I’m trying to gain an impression of what they’re like, what they might think like in all sorts of ways. ...if somebody doesn’t like me, they’re not likely to engage [with] us.”* It seems regardless of background experience or practice values, these participants pursue client boundaries, attempting to advance them towards improved sustainability.

In these initial ‘values engagements’, it appears that intuitive judgements of ‘what a client is like’ are made alongside more overt enquiries on issues of importance such as design and sustainability interests, ‘likes/dislikes’, motives and drivers. During appointment and briefing processes, practitioners examined new client priorities and formulated both explicit and intuitive assessments of such issues. Value judgements seemed to be made about the ‘type of person’ their client is—taking the form of social status, wealth, political association, profession/career, personal interests, etc. These judgements provided practitioners with beneficial psychosocial clues to approach and advance sustainability issues. Practitioners extracted and evaluated interpersonal and values-orientated information, on which they based assessments of clients, their position on sustainability, and its flexibility. These ‘indicators’ provided guidance on using situation-appropriate communication frames to achieve particular results.

Responses converged to suggest that sustainability commitment is treated initially as a boundary concept, and then a binary concept by these participants: once an estimate of a stakeholder’s boundaries is made on a spectrum of interest-versus-disinterest (which is amenable to adjustment), sustainability appears to be treated as a binary concept of accept-reject, us-them, etc. One participant explained, *“if you are starting to get some interest, you can go quite a long way down this particular line.”* The issue at hand is how far; *“that’ll very much depend on what you as an individual want; I come with my sustainability agenda and ideas, but at the end of the day, you’re the client, [...] you’re the one who says ‘well, I like the idea of [it, but] that’s not a big priority’.”*

Where the views of practitioners began to diverge can be represented by two ‘spectra’ of practitioner experience emerging from interviews: design-led and commercial-led. It became possible to detect this spectrum clearly after the analysis of participant’s use of framing and was supported by further references in their values-engagements and values-statements. Most importantly, values-engagements appear to have occurred both explicitly and implicitly, and values-statements were utilised through various forms of assessment in decision processes. One way this manifested was how sustainability decision-problems were framed and formulated—thus setting the decision-making stage.

Framing of sustainability measures appeared in the interview transcripts in a multiplicity of terms: active or passive, regulations, markets, costs, value, responsibility, ethics, life-cycle, usability, operation, maintenance, etc. The fact that one design-led practitioner acknowledges engaging with commercial clients very differently than private or public sector clients suggests that the selection of frames is multifaceted and influenced by audience, skill, experience, and values. With commercial-led practitioners, the framing of sustainability appeared heavily influenced by: cost, regulations, and usability or operations, but also to varying extents by practitioners ‘pushing the boundaries’ with their clients and regulatory authorities. This was derived from conversations with at least three different practitioners, one of whom advised these were prevailing tendencies. However, with

design-led participants it seemed the reverse: sustainability was driven by practitioner and sometimes client, with either or both pushing the boundaries; regulations represented bare minimum, lowest thresholds rather than drivers of achievement, although cost remained central. One practitioner explained how this was the case with two different clients, and appeared to intimate through body language that this was the norm in their practice. Hence, practitioners appeared to develop experience-based biases that remained present between projects. These 'biases' then informed how they framed sustainability problems to subsequent clients and stakeholders. Drawing on value judgements to inform the appropriate use of frames, the values of both practitioner and client appear to have influenced the framing of decision-problems used by practitioners, which in turn influenced decision processes. Thus, it was possible to discern that: a) framing was influenced by values, b) framing was chosen based on experience of which frames are found to speak to certain clients, and c) framing and values operated in an iterative, self-reinforcing combination.

Interestingly, it seems that the overwhelming majority of participants appeared to broadly engage with sustainability issues for their own, different reasons: some commercial; some an ethical 'altruism' and personal commitment; one an almost paternal-community spirit of responsibility. The majority of commercial-led practitioners favoured strongly promoting sustainability, but in a pragmatic manner commensurate with the requirements of their client base. This might suggest that the practitioners' individual approach does not necessarily correspond completely with the practice approach. Furthermore, the two rough groupings of participants seemed to report almost polar approaches. From the commercial-led: a 'push away from the bottom baseline', encouraging clients away from the 'only if necessary' mind-set, and client-driven cost-centred approaches. From the design-led: 'pull toward the top performance', 'shared enthusiasm', 'lead-by-example' approaches. Broadly speaking, the commercial-led practitioners' self-reporting of the 'practice environments' appear aligned more closely with (Schwartz's) extrinsic values, alongside lesser-activated intrinsic values. Design-led practice environments appear aligned with intrinsic values, whilst retaining an explicit awareness of extrinsic values-related issues.

From this group of participants, it appears plausible to suggest that values of the practitioner are reflected in three psycho-social constructs. First, the 'organisational focus' they promote (design-led or commercial-led in these cases). Second, the 'types of clients' they prefer to engage with (commercially or environmentally orientated, etc.). Third, the extent to which practitioners will continue promoting sustainability issues when resistance and barriers are encountered. Furthermore, it is also reasonable to conclude that a) the conditions of practice, combined with practitioner and client values, and the problem frames these two perpetuate can provide inhospitable conditions for sustainability, and b) that these conditions amount to cultural structural barriers to sustainability. Profit-driven extrinsic values and the stakes involved in many projects appear to allow limited scope for practitioners to engage disinclined stakeholders' intrinsic values considered more aligned with pro-environmental behaviour and support for sustainability previously demonstrated in literature.

DISCUSSION OF FINDINGS AND CONCLUSION

Decision influence processes seemed to begin during pre-engagement interactions between client and practitioner, even before an appointment was made. Beyond baseline legal regulations, the advancement of sustainability via decision processes appeared to be influenced by values and frames among this participant group. Through the practices of communicating with clients, practitioners appeared to

implicitly and explicitly elicit value statements from them and use these as heuristics and indicators to guide how to interact with them on sustainability issues, and how far and how hard to press. Intuitive judgements and cultural stereotypes of client personality and ‘positioning’ served as proxies for personality assessments and provide practitioners with heuristics with which to select appropriate methods and tactics for client sustainability engagement. In addition to values, practitioner awareness, experience, and knowledge, the heuristics of judgements, stereotypes, and personality assessments informed their choice of frames. These heuristics were used as shorthand interpretation mechanisms to influence sustainable design decision processes. They provided an interpretation method with which practitioners evaluated, and then promoted or relegated, options for engaging clients with certain frames of reference, or certain approaches to sustainability, i.e. commercial frames, energy-savings, ethical responsibility, etc. These different frames, and the values that influence them and their selection, appeared to be activated or employed either in combination or separately at different times. This occurred both intuitively and consciously in: a) implicit psychosocial interpretative and analytical mechanisms developed over time and b) explicit engagement processes.

Values engagement, elicitation of values statements, and use of interpretative mechanisms happened at an almost sub-conscious level and appeared to have gone unrecognised by the practitioners as a result. Whilst such implicit, intuitive judgements can be dangerous in the formation of false impressions and erroneous analyses, their heuristics seem to have proven useful for these experienced practitioners. However, such intangible but critically important constructs seem entirely underutilised as a resource with which to enhance performance in briefing and design for sustainable construction.

This research phase has captured certain values-influence processes, illuminating key, underlying sub-processes in sustainability decision-making, providing new insight into the conditions in which framing, values, and values engagement are relevant and useful, but under-appreciated. Responses have brought to light the subtle, nuanced, and highly individuated ways in which different practitioners approach stakeholders with sustainability issues. Given the complexity of influences, heuristics, and interrelationships, future work on this project will respond to the need to triangulate findings through further data from additional interviews, group values elicitations, and individual values surveys with design practitioners, clients, and project teams. Future work will also examine relationships in a terminal and instrumental values framework and relate them more directly to values, problem framing, and sustainability research in other fields.

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FURTHERING SUSTAINABLE BUILDING OR NOT?: DISCUSSING CONTRACTORS' REFLECTIONS ON A SUSTAINABLE BUILDING PILOT PROJECT

Sofia Lidelöw¹ and Susanne Engström

*Department of Civil, Environmental and Natural Resources Engineering, Luleå University of
Technology, SE-971 87, Luleå, Sweden*

Governmental initiatives in Sweden that aim to support the shift towards a more sustainable building stock are frequently organized as pilot (or demonstration) projects. Pilot projects have been suggested to provide platforms for learning, where for example communication can be enhanced across actors and domains, and changes in practices can be supported. However, they have also been associated with a limited diffusion of project outcomes to mainstream practice as well as difficulties fulfilling project intentions and demands regarding sustainability. In an on-going study of a pilot project for the planning and design of a housing area in a sub-arctic environment, the advancement in the understanding and use of sustainable building practices in a sustainable building pilot project is explored. Interviews were conducted with representatives of the five local contractors that participated in the pilot project, addressing their retrospective descriptions and reflections from a personal and an organizational viewpoint. In keeping with earlier sustainable building research, the project initiators' intention was to develop a shared and holistic understanding of sustainable building. Multiple stakeholders were invited to participate and during interviews the cooperation among contractors was generally put forth as a positive pilot project experience. However, our findings expose tensions between sustainable building intentions and sustainable building as operationalized in the pilot project. Three types of barriers to the advancement of the understanding and use of sustainable building practices are recognised: a skewed balance of sustainability domains; neglect of local context; and a skewed balance of stakeholder perspectives. While intangible pilot project outcomes such as these are commonly neglected, their further study could provide valuable insights into the advancement of sustainable building. Acknowledging the complexity of defining and applying sustainable building, we also propose that more attention should be paid to managing stakeholders' multiple and conflicting views in sustainable building projects.

Keywords: contractors, interpretivist approach, learning, pilot project, sustainability.

INTRODUCTION

Pilot projects are common means by which innovations (e.g. new methods/solutions) are applied and adapted to real-world situations, and have been suggested to provide platforms for learning that enhance communication between actors and domains while supporting changes in perceptions and practices (c.f. Vreugdenhil *et al.* 2012). Swedish governmental initiatives aimed at supporting the transition towards a more energy-efficient and sustainable built environment are commonly organized around pilot or demonstration projects. The Delegation of Sustainable Cities has supported

¹ sofia.lidelow@ltu.se

almost a hundred projects aiming to develop best practice examples of sustainable urban environments. The Swedish Energy Agency coordinates energy-related research including programmes such as the Sustainable Municipality initiative, which supports spearhead strategic energy projects undertaken by local authorities, and LÅGAN, which supports pilot projects on low-energy house-building. However, as noted by Femenías (2004) and Nässén *et al.* (2008), sustainable building (SB) pilot projects have had little clear impact on mainstream Swedish building practices.

The evolution of SB practices in Sweden has led to a focus on energy-efficient building. However, while energy is important, the complexity of SB requires a holistic and integrated approach that must consider all sustainability domains rather than being reduced to an overriding emphasis on a single aspect (Berardi 2013; Pan and Ning 2014). This implies also that a breadth of knowledge areas and multiple potentially conflicting stakeholder perspectives must be considered during an SB endeavour. Similar to energy and building research in general (c.f. Schweber and Leiringer 2012) SB pilot projects have typically focussed on technological innovations. However, many of the barriers blocking a shift towards SB are rooted in socioeconomic rather than technological factors (Huesemann 2003; Häkkinen and Belloni 2011; Kemp 2010). That is, despite the emphasis on “*learning for the future*” in governmental initiatives, pilot projects are typically evaluated and assessed in terms of their tangible outcomes. Relatively little is therefore known about aspects such as the stakeholders’ different interpretations and understandings of SB, their interactions, and the impacts of these interpretations and interactions on the decisions that shape the project’s ultimate results and evaluation. Nässén *et al.* (2008) called for investments in learning processes to better transfer experiences from energy-efficiency demonstrators to mainstream practice, while Pan and Ning (2014) highlighted the lack of research addressing the multiple aspects of SB through the lens of integrative stakeholders.

Adhering to calls by, e.g., Schweber and Leiringer (2012), we take an interpretivist approach to construction research focusing on learning among stakeholders from a pilot project. In an on-going study, the advancement in the understanding and use of sustainable building practices in a sustainable building pilot project is explored. The pilot project addressed in this work (henceforth referred to as the Pilot) involves the planning and design of a quarter dedicated to low-energy housing in a sub-arctic environment where there have not been many systematic attempts of this sort in the past. In an earlier part-study on the intentions and learning of the Pilot’s initiators in the local authority (Engström and Lidelöw 2015), the initiators stressed the importance of giving local contractors learning and business-development opportunities that would support them in meeting future SB-related demands. To further explore the advancement in the understanding and use of SB practices, this second part-study therefore focuses on the local contractors who participated in the Pilot and their perceptions and assessments of the Pilot. Findings are analysed and discussed in relation to the initiators’ interpreted definition of SB, and research on the complexities of defining and applying SB.

DEFINING AND APPLYING SUSTAINABLE BUILDING

The concept of sustainable development, which underpins the conceptualization of SB, is somewhat ambiguous and its definition is contested because it is complex, normative, and subjective (Martens 2006). Martens characterized sustainable development as “*a complex idea that can neither be unequivocally described nor simply applied*” (ibid.: 37). The complexity of defining and applying the idea of sustainable development and, by extension, SB (c.f. Berardi 2013) have been

recognized to stem from its dependence on time, spatial scale and domain as well as its multiple interpretations (Grosskurth and Rotmans 2005).

Time, spatial scale and domain dependences

Time dependence follows from the long-term perspective called for by authors such as Pan and Ning (2014), who emphasise the need to consider the whole building life-cycle in sustainability assessments. During their lifetime, buildings may need to undergo several changes in shape and function to meet unpredictable future requirements. To address the need for buildings to easily accommodate changes, adaptability and flexibility have emerged as key elements of SB (Gosling *et al.* 2013). Within this context, Berardi (2013) also noted that the evaluation of sustainability depends on the knowledge available at the time of evaluation; “*what is considered sustainable at one moment can be assessed as unsustainable in another*” (ibid.: 75).

Spatial scale dependence originates from the fact that construction activities have impacts at several scale levels, which raises the question of which spatial scale (e.g. that of the building components, the entire building, or the broader community) should be used in sustainability assessments (Berardi 2013). Assessments of building sustainability are often somewhat narrow, focusing on the component or building level (Pan and Ning 2014) even though SB inevitably requires consideration of the inter-connections between a building and its socio-economic, cultural and environmental context (e.g. its site, occupancy, surrounding infrastructure) (Berardi 2013). Similar to Kemp (2010), who argued that labelling a given engineering solution as sustainable is inherently wrong, Berardi (2013) and du Plessis and Cole (2011) stressed that what constitutes SB is context-specific and cannot be defined in absolute terms.

Sustainable development is often conceptually divided into multiple domains, typically including environmental, social and economic issues (Martens 2006). This division has been criticized by researchers who argue that the significance and potential of the concept stems from the interrelation among these domains (ibid.; Williams and Millington 2004). Consequently, it has been argued that SB should focus on holistic examination of these domains and their interdependencies (Pan and Ning 2014). However, as has been true of sustainable development research in general (Williams and Millington 2004) much of the effort in SB research and practice has focused on the environmental domain, overlooking many non-environmental aspects (Berardi 2013; Pan and Ning 2014). Furthermore, energy performance is the most common indicator used to evaluate buildings' sustainability (Berardi 2013). Hence, the term SB is often confused and used interchangeably with various terms relating to energy-efficient building design, technology and materials (ibid.; Pan and Ning 2014). Such reductionist approaches are incompatible with holistic examinations of SB (du Plessis and Cole 2011; Pan and Ning 2014) and risk overlooking the fact that different domains may have different and potentially conflicting aims (Martens 2006).

Multiple interpretations

Multiple interpretations of sustainable development imply that the concept is perceived and applied from diverse, frequently competing and opposing, views and perspectives (Martens 2006, Williams and Millington 2004). Consequently, SB has multiple meanings and may focus on multiple objectives because different people have different aspirations (c.f. du Plessis and Cole 2011). To help build a common vision and to deal with trade-offs, participative processes in which multiple stakeholders express and contribute their different views and perspectives on sustainability have been advocated (ibid.; Martens 2006). In contrast to the sequential

and fragmented nature of the traditional building design process, Magent *et al.* (2011) stressed the importance of interdisciplinary and iterative collaboration among actors with varied expertise and competences in the design process of SBs. By offering a common reference point for collaborating actors, visions can help provide direction and inform action to facilitate the achievement of tangible outcomes and, more importantly, to support learning outcomes that will inform further action (Kemp and Martens 2007). Learning has been identified as a core component of implementing sustainable development (*ibid.*; Scott and Gough 2003). In fact, Scott and Gough (2003) considered sustainable development to be inherently a learning process.

THE PILOT

The Pilot examined in this work involves the planning and design of a quarter in a municipality (40 000 inhabitants) in a sparsely populated region of northern Sweden. It was initiated by the local authority in 2009 to showcase low-energy and sustainable housing. The Pilot was supported by demonstration grants from Sustainable Municipality, LÅGAN and a national collaboration project between local authorities for modern wood construction. A broad constellation of stakeholders were invited to a series of activities during the Pilot, including expert-led workshops on sustainability, study trips to manufacturers and building projects constructing low-energy or sustainable housing, and meetings working towards the definition of the Pilot's sustainability criteria. These activities were followed by a series of detailed planning and design activities involving more operative task-meetings attended by a core group of participants from the local authority and the local business community.

During the Pilot, a quality programme (QP) was developed by two engaged SB experts (one sustainability consultant with a PhD in ecotechnology and environmental science, and one certified passive-house designer and architect) in dialogue with the Pilot's initiators who were active in its steering committee. The preceding expert-led workshops were intended to anchor and build support for the QP among stakeholders, and to gather their viewpoints on sustainability criteria and preconditions. The stated aim of the QP was to contribute to the sustainable development of the area containing the Pilot quarter by stipulating a higher standard for new-build than was required by the relevant legislation, in keeping with the municipality's sustainable development goals. The QP includes overall objectives for the area together with a detailed set of requirements concerning energy use, material use, water management, the indoor environment, communications, urban design, and property operation and maintenance.

METHOD

One of the authors followed the Pilot from the initiation of the detailed development planning in Jan 2010 to the last official meeting (a sales meeting) in Jan 2014. Written Pilot documentation included official minutes and planning documents, working documents, e-mail conversations, and researchers' notes from formal workshops and meetings and informal talks with the participants. Based on these documents and the results of an earlier study focusing on the Pilot initiators (Engström and Lidelöw 2015) interviews were held with the local contractors during Nov 2014 (interviewees referred to as Alpha, Beta, Gamma, Delta, Epsilon, see Table 1). The interviews, which lasted for 1.5-2 hours, were led by the author who had not previously met the interviewees, while the author who had followed the Pilot during its development participated as an observer. Both authors took notes during the interviews, which were also recorded. The interviewees were asked first to retrospectively describe and reflect on the Pilot from a personal and an organizational viewpoint. After that, the

interviews were loosely structured around three areas: the contractor's participation (e.g. incentives, scope, magnitude), the Pilot process (e.g. participants, activities, expectations, purposes), and Pilot outcomes (both tangible, e.g. new methods/solutions, and intangible, e.g. experiences/knowledge). Interviewees' perceptions and assessments of the Pilot were discussed (including factors that had supported/hindered "progress"), and the Pilot as a learning process and its learning outcomes (realised and unrealised) were explicitly addressed.

Table 1: Interviewees, representing five different local contractors participating in the Pilot

Interviewee (position)	Contractors' offering*/ No. of employees/ Net turnover (kkr) 2013	Role	Market coverage
Alpha (CEO, part-owner)	New-build of single-family houses (building envelopes erected on-site)/ 4 / 12 477	Main/sub-contractor	National
Beta (CEO, part-owner)	New-build (rebuilding, renovation) of residential (commercial) houses (components to turnkey properties)/ 14 / 49 073	Main/sub-contractor or supplier	Local/N. SE
Gamma (Plant manager)	New-build (rebuilding, renovation) residential (commercial) houses (components to turnkey properties)/ 94 / 107 461	Main/sub-contractor or supplier	Local/N. SE, FI, NO
Delta (CEO, part-owner)	New-build (rebuilding, renovation) of residential houses (structures to turnkey properties)/ 14 / 19 387	Main/sub-contractor	National, focus is N. SE
Epsilon (CEO, owner)	New-build of residential (commercial) houses (building envelopes to turnkey properties)/ 5 / 6 521	Main/sub-contractor	National, focus is N. SE

*All offer timber-framed houses produced in the region at in-house factories

The two authors have different research backgrounds: one has experience of approaching SB from a technical state-of-the-art perspective while the other is experienced in taking an interpretivist approach that acknowledges stakeholders' different and potentially conflicting interpretations of SB. In the first stage of the analysis, each author analysed the interview responses separately to identify understandings and uses of SB practices described by interviewees. The two analyses were then compared, revealing some disagreements that were resolved by consulting the Pilot documentation to provide context for the interviewees' statements. In the second stage, cross-interview analyses were performed. Similar tracks in the interviewees' understandings of SB and "proper" SB practices were identified and grouped together by each author separately, after which the two sets of groupings were compared, integrated, and collected into three themes. Finally, interviewees' retrospective reflections were analysed and discussed in relation to the Pilot initiators' interpreted definition of SB (as specified in the QP) and the SB literature.

CONTRACTORS' RETROSPECTIVE REFLECTIONS

The first theme identified from cross-interview analyses relates to the understandings of different domains of sustainability found in the interviewees' responses, and the perceived balance between these domains. The second theme relates to the context of the Pilot and the extent to which SB ambitions and QP requirements were attuned to this context. The third theme relates to the people involved in the Pilot and, more specifically, the interviewees' perceptions and understandings concerning the implications of acknowledging and liaising with individuals representing diverse areas of experience (or not) to achieve tangible and intangible Pilot outcomes.

Theme 1: Balance between domains

When reflecting on the QP requirements and the building-design suggestions put forth by the passive-house expert, the interviewees mentioned that they considered too

much weight to have been placed on the use of specific technical solutions and materials. For example, Epsilon noted that while some of the detailed solutions suggested by the passive-house expert “*were nice*”, i.e. well-suited to the buildings’ intended purpose, they had been designed without production efficiency in mind. Referring to a study-trip organized by the Pilot initiators and the passive-house expert, Alpha similarly remarked that the houses they saw might be well-designed to meet requirements concerning energy use and low-impact materials, but that they were produced in a very costly, time-consuming, non-rational way that is unfit for volume production. Further, Alpha described solutions for building adaptability suggested by the passive-house expert which Alpha believed to be based on very unlikely future scenarios (such as the need to replace the ventilation system during the lifetime of a single-family house). All in all, interviewees expressed major concerns about the costs of technical solutions and low-impact materials, implying that too little attention was paid to market and commercialization issues in the Pilot. Beta remarked that unreasonable demands (relating to energy and material requirements) affect prices and limit customers’ freedom of choice, making the building concept difficult to sell. Similarly, Alpha and Gamma suggested that one demand was being met at the expense of others, and noted that the Pilot placed little emphasis on some things that clients generally value. Alpha exemplified these arguments by stating that while most clients place high value on the views and daylight provided by windows, the houses’ window-to-wall area ratios had been reduced to meet the QP’s energy requirements.

When discussing things learned during the Pilot and their understanding of SB, interviewees typically mentioned the specific performance requirements of SB in terms of low-energy building. Gamma, Delta and Epsilon explicitly referred to “*passive houses*” and “*passive-house techniques*”, while Gamma, Alpha and Beta highlighted the importance of techniques for achieving air tightness, insulation (including material aspects), and the avoidance of thermal bridges. In addition, Delta and Gamma stated that the performance requirements of SB encompassed both technical aspects and issues of material selection relating to “*ecological building systems*”. One interviewee, Epsilon, mentioned the importance of social aspects such as health, mixed tenure forms and changing living conditions. The responses of Alpha, Beta and Gamma generally focused on the demands imposed by the technical solutions and the material selection constraints (which they considered to be too severe), and their impact on costs, commercialization, and the local market. In contrast, Epsilon argued that the Pilot had an overly narrow focus on using technical solutions to improve energy performance and that the use of costly measures to meet energy requirements may necessitate cutting back elsewhere, e.g. when selecting materials. This implies, according to Epsilon, that priorities must be set with care, and that factors such as health (which was mentioned in the context of selecting low-impact materials) must be considered before “*going after those final kilowatt-hours*”.

Theme 2: Attunement to context

Another common theme in the interviews was the need to attune SB ambitions and QP requirements to context-specific issues such as climatic conditions, the local market (preferences, willingness and ability to pay), and the Pilot’s overall objectives. For example, Epsilon stressed the need to carefully consider what people in the local market can afford (“*if it is too expensive it will not be saleable*”). Alpha, Beta and Gamma elaborated on the need to provide customers with freedom of choice, to attune the target price to the local market, and to understand local preconditions in general before making decisions regarding requirements, actions and efforts.

Expanding on the discussion above, Delta and Epsilon both noted the need to attune energy requirements to the Pilot's SB ambitions. They stressed the specific need to not renounce requirements regarding low-impact materials to reach the lowest energy use possible, which they thought had been the case in the Pilot, despite the more holistic SB ambitions. Epsilon extended this line of reasoning by elaborating on SB, viewing the Pilot buildings in relation to the overall objectives for the urban area (in line with the QP). Together with Gamma, Delta and Epsilon further described the need to adopt a more long-term perspective when engaging in Pilots such as this one, e.g., in terms of long-term business and commercialisation opportunities for SB and low-energy houses. Gamma also stressed that since clients in general do not necessarily value low-energy houses in and of themselves, their life-cycle and operating cost advantages should be communicated to the client rather than focusing on their investment costs.

Elaborating on the importance of careful design and different acts of verification, Alpha expressed concerns about whether such competences were regionally accessible. Alpha also deemed the passive-house concept to be far too demanding for his company to produce given the time and effort needed to produce detailed solutions to avoid thermal bridges and air leakages, to determine whether materials and components such as windows comply with requirements, and to perform verifications.

Theme 3: Acknowledge and liaise with multiple areas of expertise

As previously expressed by the Pilot initiators (Engström and Lidelöw 2015), the Pilot was organized with the explicit intention of gathering multiple competences and perspectives. The need to acknowledge and liaise with multiple areas of expertise (know-what, know-who, know-how) was another recurring theme in the interviews. Delta described entering the Pilot with the intention of learning about passive-house techniques. However, based on their interactions with other participating stakeholders, Delta described the emergence of a revised view of SB acknowledging e.g. the use of low-impact materials to be as important as low energy use.

When assessing the Pilot process, Delta stressed the importance of enabling different actors to come together, stating that the arena created by the local authority for the different stakeholders to meet and interact had turned out to be more important than the Pilot itself. Similarly, Gamma noted that the Pilot had provided the resources necessary for experts of many sorts to interact. The cooperation among contractors that emerged during the Pilot was particularly highlighted by the interviewees as a positive experience. Alpha described how the contractors came to visit each other's factories and thus gained insights into alternative ways of production. Delta described how the contractors had been obliged to open up to one-another in order to advance the Pilot, learning from each other and becoming less protective of their business practices. Epsilon described exchanges and joint elaboration of ideas to illustrate how the contractors came to cooperate during the Pilot, and Gamma stressed the significance of contractors exchanging knowledge, experience and even openly discussing cost estimates and calculations. According to Delta, an unexpected but important experience was that the open, "*guards-down*" cooperation had no drawbacks. Contrary, new opportunities had emerged and Delta and Epsilon stated that they had on-going plans for further business cooperation outside the Pilot.

Reflecting on the Pilot, the interviewees observed that while the project had gathered multiple competences, market experts had been excluded. Alpha suggested that a local real estate agent should have been included in the Pilot to provide insights regarding the local market and counterbalance the passive-house expert's perspective. Moreover, although contractors had been invited to participate in the expert-led

workshops together with, e.g., local authority officials, and the Pilot workshops were aimed at developing a shared understanding to support SB, interviewees stated that their experiences and points of view were not always taken into account (this was also noted by Pilot initiators; Engström and Lidelöw 2015). Alpha perceived that the contractors were expected to attend the workshops to “*listen and learn*” rather than to share their viewpoints and critically review experts’ suggestions. Beta pointed out as an important learning experience from the Pilot the significance of not only engaging contractors early on but of actually listening to them, i.e. taking their views into account. In line with Alpha and Beta, Delta stressed the importance of listening to one another (i.e. participating stakeholders with different experiences and understandings) to avoid specific considerations being given too much emphasis at the expense of others. The passive-house expert possessed a lot of knowledge which was willingly shared, Delta thought, but there was a lack of recognition of contractors’ input.

REFLECTIONS DISCUSSED BASED ON SUSTAINABLE BUILDING RESEARCH

Whereas researchers such as Williams and Millington (2004) and Martens (2006) argued that the significance and potential of sustainable development lies in the interrelation among domains, a skewed balance was described by the interviewees. Interviewees’ reflections suggest that, typically, SB was confused with energy-efficient building which is not uncommon according to the review of Pan and Ning (2014). Supporting also the notion by Pan and Ning (*ibid.*) that efforts in SB often are concerned with environmental aspects and disregard other domains are interviewees’ remarks regarding the costs of energy-related solutions causing cutbacks elsewhere, and limited attention being paid to market and commercialization issues. As strongly argued by the interviewees, one significant consequence of neglecting commercial factors is a reduction in the saleability of the resulting buildings. This suggestion is supported by the fact that, to date, no houses have been built in the Pilot quarter.

Interviewees’ Pilot reflections provided some new insights relevant to the academic discussion regarding the time- and spatial-scale dependence of SB. First, the interviewees described a long-term perspective on SB that seems more strongly linked to market and commercialization issues than to buildings’ adaptability and flexibility. Interviewees questioned the relevance of solutions for building adaptability which were suggested by the passive-house expert, stating that accounting for very unlikely scenarios is costly and may be impractical from a production-efficiency perspective. In addition, the tendency among researchers (noted by Pan and Ning 2014) to narrow down the spatial scale when assessing sustainability was also apparent in the interviewees’ reflections. Although Epsilon acknowledged the implications of SB on a broader spatial scale, including the interconnections between the building and its context, interviewees typically related SB to the component and/or building level. Third, supplementing the building-context relation emphasized in SB research, Alpha presented a process based-view of spatial-scale dependence by raising concerns over the accessibility of the competences required to implement SB practices.

The precedence of a single sustainability domain (i.e. the environmental and, to some extent, the social domains) or individual aspects of one domain (i.e. energy use, air tightness, etc.) over others (economic and socioeconomic aspects) seems to have counteracted the holistic perspective that is advocated in the SB literature and which the Pilot’s initiators wished to propagate. Specifically, whereas the initiators’ intention was to develop a shared and holistic understanding of SB, our findings suggest that

the interviewees had varied understandings of the concept and that they and other participants during the Pilot came to take a reductionist approach to the complexities of SB. The interviewees' notion that local-market preconditions were insufficiently accounted for during the Pilot suggests that a reductionist approach was adopted even during the development of the QP, which focused strongly on environmental aspects.

The Pilot appears to have been organized in line with calls in SB research for collaboration among multiple expertise and competences (Magent *et al.* 2011) and for participative processes in which multiple stakeholders can express and contribute their different views and perceptions (e.g. du Plessis and Cole 2011). The interviewees highlighted the opportunities to meet and interact with different actors as a key positive outcome. However, they noted a lack of experts representing the economic domain from the market perspective to balance the input of engaged SB-experts. Interviewees also called particular attention to the significance of listening to all of the stakeholders' views in addition to inviting multiple stakeholders to participate.

CONCLUSIONS

Benefits of the Pilot that were highlighted by the contractors seemed to include “*learning outcomes*” stemming from the provision of an arena that enabled different stakeholders to meet and interact. In some cases this seems to have supported revised perspectives on SB, changes in business practices, and the formation of new business relationships. However, our findings also expose tensions between SB intentions and SB as operationalized in the Pilot. Our assessment of the contractors' reflections revealed three types of barriers to the advancement of the understanding and use of SB practices: a skewed balance of sustainability domains, the neglect of local context, and a skewed balance of stakeholder perspectives. In line with SB research and the contractors' suggestions, the skewed balance of domains and neglect of local context in the Pilot could potentially have been counteracted if, for instance, trade-offs between different domains and requirements and the inclusion of opposing views had been managed differently. Our findings suggest that some stakeholder perspectives could have been more thoughtfully represented but also more explicitly accounted for.

To date, there has been little research on the integration of multiple stakeholders for SB delivery (see, e.g., the review by Pan and Ning 2014). However, engaging multiple stakeholders is commonly recognized as “*good practice*” in the planning and design process, particularly for SB. Thus, underscoring Scott and Gough's (2003) view of sustainable development and its implementation as a learning process, we propose that the management of stakeholders' multiple and conflicting views requires further attention. Based on our findings we also suggest that further studies on the intangible outcomes of SB pilot projects, such as different stakeholders' understandings of SB's benefits and the barriers to its implementation, could provide important insights into factors affecting the adoption of SB principles in mainstream practice.

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DEVELOPING A SUSTAINABILITY ASSESSMENT TOOL TO AID ORGANISATIONAL LEARNING IN CONSTRUCTION SMES

James Upstill-Goddard¹, Jacqui Glass², Andrew Dainty³ and Ian Nicholson⁴

¹*Centre for Innovative and Collaborative Engineering, Loughborough University, Loughborough, UK*

^{2 and 3}*School of Civil and Building Engineering, Loughborough University, UK*

⁴*Responsible Solutions Ltd., Loughborough, UK*

Organisations engage with sustainability for a number of reasons, often implementing standards to demonstrate commitment to sustainability or benchmark performance. However, many scholars discuss sustainability from an operational or administrative perspective, largely neglecting the role of individuals making up the organisation. Central to organisational development are the learning processes of these individuals and how these translate into organisational learning. Although research into organisational learning is abundant, relatively little is known about how construction organisations, particularly those classified as SMEs, undergo learning processes in order to increase their knowledge. Furthermore, organisational learning requires high absorptive capacities (ACAP) and previous research has linked this with successful standard implementation. SMEs are often pressurised by customers to obtain certification to multiple standards, yet often lack the necessary expertise, and financial and time resources to implement these. This research argues that organisational learning is a key limiting factor in successful sustainability standard implementation. Specifically, the development phase of a sustainability self-assessment tool to identify environmental and social aspects most relevant to an organisation's operations is presented. Following this, the tool then enables the level of organisational knowledge held about each of these aspects to be determined such that learning approaches are informed to increase learning and knowledge and hence absorptive capacities. The main components of this assessment tool are presented and rules for its operation and development established. Next steps for the assessment framework and suggestions for its applicability to construction product manufacturers are also offered.

Keywords: absorptive capacity, corporate social responsibility, organisational learning, sustainability assessment, sustainability standards.

INTRODUCTION

Demonstrating commitment to sustainability and enacting positive change to incorporate greener behaviours at the organisational level is often evidenced via certification to sustainability standards. Standards are adopted to demonstrate the performance of the organisation or their products against specific areas. They are voluntary and comprise a list of statements providing guidance and requirements on commonly accepted norms under these specific areas. Many studies have considered the role that these have from an operational or administrative perspective, such as how certification to ISO 14001 (BSI, 2004) for environmental management impacts on

¹ j.d.upstill-goddard@lboro.ac.uk

organisational performance (e.g. Link and Naveh, 2006). While certification to standards has been found in many cases to hold significant benefits, such as improved legitimacy (Bansal and Hunter, 2003), cost savings (Raines, 2002) and increased trade opportunities (Prakash and Potoski, 2007) in the case of ISO 14001 (BSI, 2004), it is also argued that the expense associated with implementing them and the intensive demands placed upon staff and time resources often render them unattainable for many organisations, particularly small and medium sized companies (SMEs).

However, the increased focus on sustainability assessment in supply chains (Varsei *et al.*, 2014), coupled with the growing interest in product stewardship (Schroeder (2012), for example), is creating increased demand for evidence of certification to sustainability standards within product supply chains. Consequently, 'voluntary' standards are becoming ever more 'quasi-voluntary', which SMEs struggle to engage with due to resource constraints (Cassells and Lewis, 2011). Within the construction industry, clients tend to prioritise suppliers that can demonstrate compliance with standards over those that cannot, meaning that increasingly certification is becoming a key factor in awarding supplier contracts.

Such operational and administrative issues are not the only barriers to certification however; high levels of absorptive capacity are suggested as a necessary prerequisite for sustainability certification given the learning required to comply with, and maintain certified performance under, such evolving standards. Indeed it is argued here that learning represents perhaps the most significant barrier to complying with standards, and the lack of resources that SMEs typically possess affects their ability to effectively learn. Cost-effective practical tools are therefore required to support this learning, yet there is currently a paucity of such tools available to construction SMEs. Questions remain, however, as to the form that sustainability assessment tools should follow to increase learning within construction SMEs such that they can comply with sustainability standards. This research establishes principles to support construction SMEs in establishing any gaps in compliance and in identifying learning actions to effectively manage sustainability issues. These principles can then be used to govern the design of a framework to aid in the development of a more detailed tool. It is important at this point to highlight that such principles and the tool are not confined to SMEs however and as such may be applicable to non-SME organisations. The tool is specifically targeted at SMEs in this research due to their relative struggles in complying with sustainability criteria.

IMPLEMENTING SUSTAINABILITY STANDARDS IN SMES

SMEs are often considered to have fewer than 250 employees, a turnover of less than €50 million and make up around 99% of all businesses (European Commission, 2013). Collectively they contribute to about 60% of commercial waste and 80% of pollution in the UK (Cassells and Lewis, 2011), but when considered individually, their impacts are regarded as relatively low (Brammer *et al.*, 2011). Jenkins (2006) argues however, that there is growing recognition of their collective environmental and social impacts, with Russo and Perrini (2010) even suggesting that sustainability holds greater importance for them than for their larger counterparts due to their stronger links with local communities.

Much has been written in the sustainability and supply chain management literature about how SME engagement with sustainability is hampered by tight resource constraints (e.g. Ciliberti *et al.*, 2008; Lepoutre and Heene, 2006). Implementing a sustainability standard is a resource-intensive process, requiring the provision of vast

financial resources (Revell and Blackburn, 2007) and commitments in time from staff who also hold other responsibilities within the business. Although there is often considerable overlap between many of these sustainability standards, such as that of ISO 14001 (BSI, 2004) and BES 6001 (BRE, 2014), they are rarely implemented in a coherent and holistic manner. Furthermore, SMEs do not possess the resource to implement multiple standards simultaneously (Tsai and Chou, 2009).

Research has also shown that customer pressure can drive adoption of standards (Delmas and Montiels, 2009), often more so than the organisation's technical capacity to implement them (Simpson *et al.*, 2012). In a UK construction context, where 950,000 SMEs operate (BIS, 2014), standards are only implemented by product manufacturers at the request of customers. Hence, implementation is only considered by the SME when it has sufficient resources and demand from customers to warrant certification. However, resources and demand aside, learning is argued to be a key barrier to successful standard adoption in the SME, and implementation of standards can be linked to the organisational knowledge and learning structures that are in place.

Sustainability standards represent an important area for the SME, yet without the in-depth knowledge of how to implement such standards, they often struggle to keep up with the demands of their clients. Therefore, facilitating learning when implementing a sustainability standard is an important but rarely considered area for research.

LINKING STANDARDS AND ORGANISATIONAL LEARNING

Implementation of standards can be thought of as a change process requiring organisational learning (Maon *et al.*, 2009) and the knowledge obtained from this learning can affect SME commitment to sustainability (Halila, 2007). However, the majority of SMEs are 'vulnerably compliant' according to Perrini (2006), as they do not possess sufficient knowledge to ensure full compliance with sustainability requirements. Therefore, in order to increase uptake of sustainability among the SME community, provision and facilitation of learning holds great significance.

Organisational learning has been shown to be highly dependent upon the absorptive capacity (ACAP) of the organisation (Kim, 1998). ACAP is the ability of a firm to create competitive advantages through implementation and exploitation of knowledge and new resources (Cohen and Levinthal, 1990; Zahra and George, 2002). ACAP has been linked with effective development of environmental strategies (Delmas *et al.*, 2011) and sustainable performance improvement in supply chains (Sáenz *et al.*, 2014), and in a construction context, green innovation and performance (Gluch *et al.*, 2009). An important component of ACAP is knowledge acquisition, which is key for sustainability innovations (Halme and Korpela, 2014), as those organisations that engage in regular knowledge acquisition activities tend to exhibit greater environmental commitment (Roy and Thérin, 2007).

It is thus posited that providing knowledge acquisition opportunities can not only mobilise learning for the SME, but can also encourage a more proactive attitude to sustainability issues. Potentially, SMEs can then become effective 'transmitters' of sustainability throughout the supply chain (Ayuso *et al.*, 2013); therefore ensuring SME engagement with sustainability can be important in increasing supply chain sustainability.

Through the provision of a learning tool for the SME, this increase in supply chain sustainability can be obtained. This tool should not only support meeting the requirements of standards, but also ensure SMEs have the necessary expertise to

obtain added value from implementing these standards. There are however a wealth of standards in the public domain, potentially creating a confusing landscape. Therefore a tool should also consider those issues most significant to an SME, such that performance in those areas of most significance to its operations is prioritised. The following sections of this paper will look at the development of a framework upon which such a tool could be based.

DEFINING THE PRINCIPLES FOR THE ASSESSMENT FRAMEWORK

1. Prioritising of issues based on risk

Integrating sustainability requires a systems approach with an appropriate management framework (Azapagic, 2003). Reporting frameworks, such as the Global Reporting Initiative (GRI, 2013), encourage organisations to consider different sustainability aspects depending on whether they represent material issues. Likewise, the new ISO framework (IRCA, 2014) requires an organisation to look at its context and how this governs those internal and external issues that it deems to be significant. The latest version of the GRI guidelines (G4) lists 91 sustainability indicators under 46 different aspects, split into seven broad sections. Clearly, reporting against all these indicators would constitute a considerable task, particularly for an SME. Although this is not expected by the GRI, it does highlight the wide range of issues that could be considered relevant to sustainability. It is however plausible to suggest that even conducting a materiality assessment to identify and address the list of ‘material’ issues would still represent a significant challenge for many SMEs. This example of GRI indicates that such a leading framework to guide sustainability reporting (Brown *et al.*, 2009) is inappropriate for SMEs, as its demands are too onerous for organisations with limited resources.

Some standards however, are rather more prescriptive in what they require compliance with. For example, anecdotal evidence highlighted the case of a construction product manufacturer that was forced to create documentation and policy statements around efficient use of water, as this was required under BES 6001 (BRE, 2014), despite the fact water did not constitute a significant issue for that organisation. In this case, the sole reason that the organisation pursued this issue was to score more ‘points’ under BES 6001 (BRE, 2014). De Colle *et al.* (2014) cite a similar example, where an assessment tool that was used by two oil companies was designed in such a way that high scores could be obtained by focusing on questions where it was easiest to score points, rather than where the highest risks occurred. Perversely, this could lead to an organisation scoring a ‘high’ level of sustainability performance against the tool, even though it may score poorly against individual ‘high risk’ issues.

An organisation’s assessment of risk can be linked to management of its reputation (Bebbington *et al.*, 2008) and thus those issues that have a greater potential to cause reputational damage are often considered issues of higher risk. The significance of an individual aspect can be defined by how much of an impact it has on the environment, society or economy. Furthermore this significance of an aspect is directly linked to risk; poor management of individual aspects that are deemed significant might cause greater risks to the organisation’s reputation, leading to potential negative or unwanted attention from stakeholders or the media.

Reputational drivers have been shown to be core reasons for an organisation to adopt the GRI (Nikolaeva and Bicho, 2011) and in a construction context, engaging with

responsible sourcing has been linked to reputational issues (Upstill-Goddard *et al.*, 2013). Clearly, taking actions to protect reputation holds great significance; such a risk assessment can aid an organisation in prioritising areas for attention. Therefore, we can arrive at our first principle for our proposed framework: it must initially seek to identify sustainability aspects that are most significant to the organisation in terms of risk, such that performance improvement against 'high risk' aspects is prioritised.

2. Developing the modular approach

Once significant aspects have been identified, the organisation can then begin to address each of these in a systematic way. By setting a uniform framework for the assessment of each sustainability aspect, a standardised approach to obtaining management and performance improvements for each aspect can be developed. Such a framework should focus on breaking down the requirements of management system standards to render them more approachable for an SME, as many such standards are developed with the aim of targeting primarily big businesses (Enderle, 2004). For this reason, the framework will take a 'modular' approach, with different aspects each representing one module.

Clearly, the first step for any assessment tool is to establish the current position of an individual organisation with regard to individual aspects. Methods such as gap analyses (used at the start of a BES 6001 (BRE, 2014) implementation project, for example), use of maturity matrices (used to guide development of BS 8903 (BSI, 2010) for sustainable procurement), and baseline data collection (such as an initial environmental review used in an ISO 14001 (BSI, 2004) environmental management system (EMS)) can all be used to establish current performance level. Operational controls can then be set, which could be formalised through the setting of control procedures and objectives and targets to strive for performance improvements. BES 6001 (BRE, 2014) sets requirements for organisations to develop a 'documented management system' for many of the environmental and social aspects covered by the standard. This requires an organisation to set a policy, metrics and objectives and targets for specific issues, enabling effective management of each aspect. In this proposed framework, such documentation is concerned with developing and designing the management processes for each aspect.

Once the 'Design' stage has been completed, and procedures are in place for managing each aspect, the organisation can then begin to implement these. This should ensure that all procedures are fully embedded within the organisation, data are collected, monitored and measured and training and awareness raising activities are conducted (see Azapagic, 2003). Organisations could also use this stage to implement auditing activities to ensure procedures are correctly being carried out and data collected are accurate. These activities should be termed the 'Implementation' stage of the framework. Full engagement at this stage should cause the organisation to have fully operational robust processes to manage different sustainability issues.

However, in order to set further improvement targets and strive for these on an on-going basis, the proposed framework should also include a 'Review' stage, where all data are reviewed and any necessary corrective actions emanating from audits are advised. This can then contribute towards a 'continual improvement' culture, as advocated by many of the ISO management systems.

It is therefore suggested that each 'module' is based upon this 'Design, Implement, Review' process, which is similar to the 'Plan-Do-Check-Act' approach suggested in the ISO 14001 (BSI, 2004) standard. Therefore, the second principle for the proposed

assessment framework has been determined: it must address all significant aspects in a modular way following a systematic approach, as outlined above.

3. Prescribing learning approaches to improve sustainability management

A criticism often levied at standards is that they tend to encourage a ‘box-ticking’ approach to compliance, where specific clauses are implemented with little consideration as to how they bring a wider benefit to the organisation (De Colle *et al.*, 2014). This can directly lead to standards actually failing to improve performance (Simpson *et al.*, 2012), which somewhat contradicts the reasons behind their implementation. As such, our assessment framework should seek to avoid prescriptive actions that could potentially cause a ‘box-ticking’ approach to any tool that is developed out of it. Given the links already made between sustainability standards and organisational learning, it is suggested that this framework should look to prescribe learning actions for each aspect by determining what knowledge the organisation possesses about the requirements of the sustainability standards.

Considering the systematic nature of the modules as discussed previously, learning actions should focus on the design, implementation or review of a particular module. It is suggested that by formulating a question set for each module that considers those topics core to complying with that module, any tool could determine the gaps in the organisation’s knowledge about that specific module and as such, can highlight areas where further learning might be required. This will ensure that organisations can implement standards in a way that adds value to their operations. As such, ACAP can be increased, as organisations are essentially ‘learning-by-doing’, which aids in increasing their transformation of knowledge (see Zahra and George, 2002). The third principle for the development of the framework is thus set: it should relate the knowledge gaps of the organisation to the requirements of the sustainability standard and prescribe learning actions where these gaps exist.

Figure 1 shows how these rules fit within the high-level design of the framework. This framework can then be used to guide development of the assessment tool.

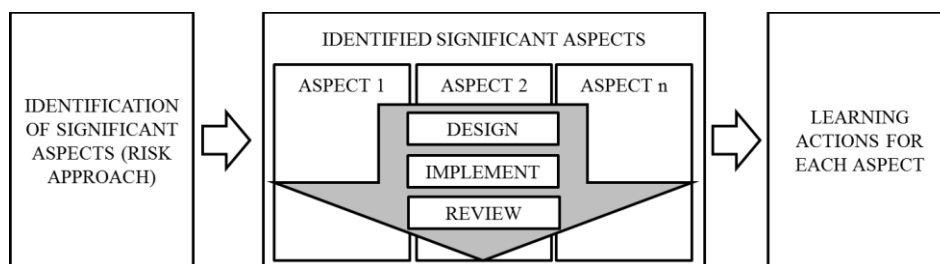


Figure 1: The high level framework according to the development principles established.

APPLICATION OF THE TOOL: A LEARNING DIMENSION

The high-level framework developed above can be used to guide the development of a sustainability assessment tool, which can be used by an organisation to address either the requirements of a specific sustainability standard or to address broader corporate responsibility requirements. As explained in the previous section, the final stage of the framework (labelled as 'learning actions for each aspect' in figure 1) will need to understand what the organisation is required to do and their awareness around these requirements. This will enable the prescription of learning actions for the organisation such that it can obtain sufficient knowledge to address the requirements of the

modules it is addressing. Implicit in the framework is that organisations need to adopt a 'learning organisation' form (Senge, 1990). The type of learning that an organisation undergoes is dependent upon its culture (Love *et al.*, 2000); therefore an organisation's learning is dependent upon the level of individual learning. Management system standards, such as ISO 14001 (BSI, 2004), stress the significance of training programmes, but it is imperative that such activities are fully implemented and their importance fully recognised, as Tennant and Fernie (2013) report that ad hoc delivery of management-led training does not maximise the potential for learning.

If this framework is to assist in the delivery of effective learning for employees, it must ensure that full commitment is given to the learning activities prescribed within the framework. These should be planned, and organisations using the framework will need to set aside time for employees to undergo any learning activities. However, given the tendency for the SME to possess limited time resources (Lepoutre and Heene, 2006), such learning activities developed as part of the tool will need to focus on short 'bitesize' activities, such that the effect of time constraints is minimised.

CONCLUSIONS AND RECOMMENDATIONS

This research paper has presented the principles and some components of a learning framework, which will be used to guide the development of a sustainability assessment tool. The framework rests on three principles: Firstly, the tool must identify those sustainability aspects most significant to an organisation's activities such that resources can be concentrated on key aspects; secondly, the framework should follow a modular design, with each individual aspect representing one 'module', so significant aspects are addressed in a systematic way; and finally, the framework should establish knowledge gaps and link these to the requirements of sustainability standards, thereby prescribing learning actions that will aid in the organisation complying with standards. This enables an SME to undergo learning to ensure that the requirements of sustainability standards are complied with. It also enables an organisation to increase its learning and knowledge and hence absorptive capacities (ACAP).

These principles also govern the three high level components of the framework under which the detailed modules and questions will be developed. Next steps will consider the development of individual modules using the principles presented by establishing what is required by different standards against specific aspects. Within each of these individual modules, question sets to understand the knowledge held about each aspect will be developed according to the modular principles established. The framework must however also seek to be free of any limitations, and as such, development must focus on avoiding a 'box-ticking' approach to compliance. This will be addressed by extracting the organisational performance intricacies for different aspects and setting bespoke learning objectives in order to provide added value to the sustainability standard being implemented.

Finally, the development of the framework presented here contributes specifically to literature linking learning and ACAP with improved sustainability performance in supply chains. An assessment tool developed by use of this framework will enable an organisation to set proactive sustainability strategies by focusing on learning and development outcomes which lead to increased organisational learning and hence ACAP. Furthermore, by considering the ability of SMEs to 'transmit' sustainability through the supply chain (Ayuso *et al.*, 2013), this framework can provide a useful starting point for wider sustainability adoption.

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ANALYSIS OF THE RELATIONSHIPS BETWEEN MINDFULNESS AND STRESS FOR CONSTRUCTION PROFESSIONALS

Qi Liang¹ and Mei-Yung Leung

Department of Architecture and Civil Engineering, City University of Hong Kong, Tat Chee Avenue, Kowloon Tong, Hong Kong

Stress can result in significantly negative consequences to individuals, organization, and society. Various stress reduction methods have been implemented to reduce stress, including mindfulness-based stress reduction (MBSR) that teaches individuals to cultivate mindfulness to release stress. Although it has been confirmed that mindfulness can release stress, relative contribution of each mindfulness characteristics to stress reduction remain unknown. Hence, this study sets out to fill in the research gap in the context of construction industry. A questionnaire was designed and distributed out to construction professionals. Purposive sampling has been adopted to control the quality of the data, and a total of 84 responses were received. A series of statistical techniques are applied to analyze the collected data for testing the reliability and validity of the questionnaire, and for investigating the relationships between mindfulness characteristics and stress. Factor analysis and reliability test determine ten mindfulness characteristics, including attention, patience, beginner's mind, trust, self-compassion, non-reaction, non-judging, non-striving, letting go and description; and four kinds of stress, including quantitative stress, qualitative stress, emotional stress and physical stress. The results of the study reveals that (1) non-reaction and self-compassion can release quantitative stress, while trust and non-judging can exacerbate it; (2) non-reaction can reduce qualitative stress, while attention increases it; and 3) non-judging and description can relieve CPs' emotional stress, while non-striving will exacerbate it. Based on the research findings, several practical recommendations were proposed to construction organization and construction professionals, including developing emergency response guidelines and promoting the value of self-compassion. This work determined the effect of mindfulness characteristics on stress of construction professionals, which enhance the knowledge of stress management in the construction industry.

Keywords: construction professionals, mindfulness characteristics, stress.

INTRODUCTION

The construction industry is characterized by its complicated, dynamic, and uncertain environment, all of which can induce stress for construction professionals (CPs). In fact, the majority of CPs have been shown to be suffering from stress as a result of working in such a challenging industry (CIOB 2006). Failure to effectively cope with stress not only leads to emotional and physical health problems to individuals, but also negative consequences to organizations (Health and Safety Council 2007; Leung *et al.*

¹ qiliang3-c@my.cityu.edu.hk

2008). Accordingly, effective stress management is critical to the success of any construction projects.

Due to personal differences in terms of experience, age, and personality traits, CPs will adopt different coping behaviors, adaptive and/or maladaptive, to deal with stress (Leung *et al.* 2006). Mindfulness-based stress reduction (MBSR) has been used to enhance individuals' level of mindfulness and, in turn, help them to cope with stress (Kabat-Zinn 2001). This has been recognized as good for individual wellbeing and the reduction of distress (Nyklicek and Beugen 2013). Mindfulness as a concept consists of several different characteristics (Cardaciotto *et al.* 2008), but so far no investigation of their respective effects on managing stress in CPs has been carried out. This study therefore set out to investigate the relationship between mindfulness characteristics and four kinds of stress experienced by CPs using a scientific research methodology.

STRESS

Stress is prevalent in the construction industry. It can have negative consequences for individuals and organizations, such as lost productivity, reduced morale, and high turnover (Lossemore and Waters 2004). Job stress results from the source of stress, which resides in the working environment. It occurs when there is a discrepancy between an individual's self-perceived and actual ability to deal with tasks (Edwards 1988). Job stress can be either quantitative or qualitative depending on its source (Gmelech 1982). Quantitative stress is defined as the stress resulting from the quantitative discrepancy (i.e., volume of work) between external demands and individuals' actual ability, while qualitative stress is defined as the stress resulting from the qualitative discrepancy (i.e., difficult of work) between external demands and individuals' actual ability (Leung *et al.* 2014). Quantitative and qualitative stress can be induced by stressors like work-home conflict, work underload, etc. (Leung *et al.* 2007), while chronic exposure to quantitative and qualitative stress can induce burnout, decreased organizational commitment, and lower productivity among CPs (Leung *et al.* 2011).

Facing source of stress could result in emotional stress to individuals, which manifests itself in the form of worry, anxious and being frustrated (Gmelch 1982). This could further lead to emotional exhaustion if individuals are continuously affected by the source of stress (Babe *et al.* 2009). In addition to negative individual consequence, emotional stress also induces negative consequence to organization, such as absenteeism, loss of productivity, diminished organizational commitment (Finney *et al.* 2013).

Exposure to stress can also provoke the physical adjustments of the human body, such as increased pulse rate, increased blood pressure, and sweating (Schat *et al.* 2005). Over certain time these physical adjustments cannot revert into normal, and physical stress symptoms will result and appears in the form of headache, back pain, and loss of appetite (Mellner *et al.* 2005). Physical stress is particularly detrimental, as in addition to impair performance, prolonged suffering from it will also result in future morbidity and mortality (Nixon *et al.* 2011).

MINDFULNESS

The transactional model suggests that individuals cognitively process information about sources of stress, and then utilize their resources to cope with them (Ganster and Rosen 2013). However, CPs will adopt either adaptive or maladaptive coping

behavior to cope stress (Leung *et al.* 2014). It has been confirmed that MBSR can lead to adaptive coping and stress reduction. For instance, various mindfulness cultivation practises, such as mindful sitting, walking and stretching can lead to positive emotion (Mace 1956), and thus, facilitate the coping process through converting negative appraisal into a positive one and enable the individual to sustain motivation and coping efforts over the long term (Folkman 2010).

MBSR is a clinical program consisting of specific instruction and guidance in mindfulness practice, which intends to cultivate one's mindfulness (Kabat-Zinn 1982). Mindfulness is psychological concept, and has been defined as the process of pay attention in a particular way with present focus, non-judgment, awareness, curiosity, and so on (Kabat-Zinn 2001). In addition to facilitate adaptive coping behaviors, the cultivation of mindfulness through MBSR can be also helpful for relieving stress, mitigating depression, improving physical and mental fatigue, and optimizing task and interpersonal performance (Carmody and Baer 2008). Moreover, mindfulness has wide applicability to every people in spite of their occupations, cultures, and countries (Franco *et al.* 2010).

Some studies of mindfulness have identified a wide range of mindfulness characteristics, including attention, awareness, acceptance, being non-judging, and present focus (e.g., the Five Facets Mindfulness Questionnaire by Baer *et al.* 2006; the Philadelphia Mindfulness Scale by Cardaciotto *et al.* 2008). Although the overall benefits of mindfulness have been well acknowledged, the individual effect of various mindfulness characteristics remains unknown. Given that the comprehensiveness of the mindfulness' definition, this study examines the individual effect of a total of ten mindfulness characteristics that can be cultivated by MBSR, including attention, patience, beginner's mind, trust, self-compassion, non-reaction, non-judging, non-striving, letting go and description.

CONCEPTUAL MODEL

Based on the literature review, a conceptual model has been established to reflect the hypothesized relationships between mindfulness characteristics and stress (see Figure 1). We hypothesized that the ten mindfulness characteristics (i.e., attention, patience, beginner's mind, trust, self-compassion, non-reaction, non-judging, non-striving, letting go and description) can help to release four kinds of stress (i.e., quantitative stress, qualitative stress, emotional stress and physical stress).

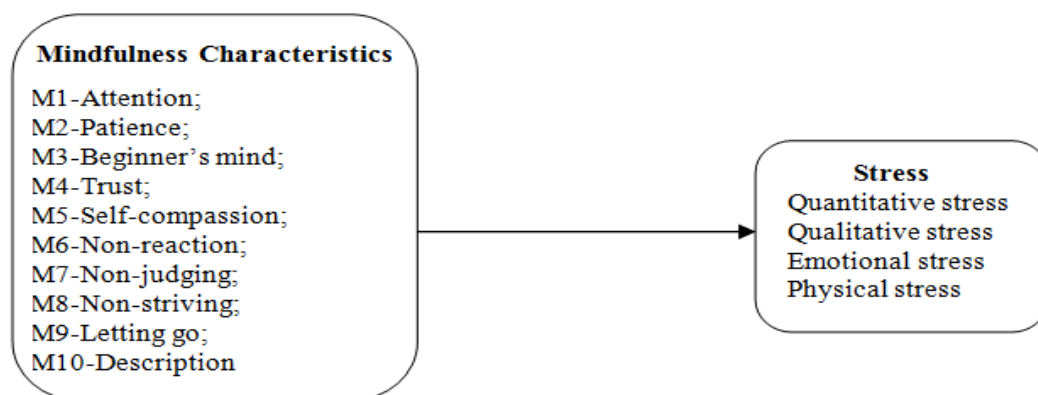


Figure 1 Conceptual Model of Mindfulness-Stress for CPs

RESEARCH METHOD

Measurement

This study focused mainly on CPs with experience of working on construction sites. Based on the extensive literature and our conceptual model, a questionnaire was designed and administered with CPs in Hong Kong to investigate the relationships between stress and mindfulness characteristics. In addition to questions capturing personal information, the survey included scales measuring the mindfulness characteristics (Baer *et al.* 2004, 2006; Brown and Ryan 2003), quantitative and qualitative stress (Leung *et al.* 2008), and emotional and physical stress (Leung *et al.* 2011). All responses were measured using a 7-point Likert-type scale ranging from 1 (strongly disagree) to 7 (strongly agree). As all the scales in the questionnaire have been tested and validated by previous studies (Cardaciotto *et al.* 2008; Leung *et al.* 2008, 2011), this questionnaire is reliable in terms of measuring the underlying constructs and free from random error (Pallant *et al.* 2011).

Sample

Purposive sampling was adopted to control the quality of the data (Patton 1990). A total of 450 questionnaires were distributed to CPs working for developers, public sector employers, main or subcontractors, consultancy firms, or related organizations in Hong Kong. Out of the 450 questionnaires, 84 were returned, giving a response rate of 18.67%.

RESULTS

Factor Analysis and Reliability Analysis

A principal component analysis (eigenvalue-1 cutoff) was applied to reduce the huge amount of items into meaningful factors (Pallant *et al.* 2011). The results confirm ten mindfulness characteristics, and four kinds of stress, with the factor loading of each item ranging from 0.614 to 0.910. Given that the sample size is 84, all the factor loading values are acceptable (Hair *et al.* 2010). To assess the internal consistency of these factors, reliability analysis was conducted using Cronbach's alpha, the most widely used measure. The measures of all ten mindfulness characteristics and four kinds of stress showed acceptable alpha values ranging from 0.661 (beginner's mind) to 0.912 (openness) (Hair *et al.* 1998).

Regression Analysis

Since mindfulness as conceptualized here consists of ten characteristics, it is worthwhile to identify which may make unique contribution to stress reduction. Multiple regression, as one of the sophisticated statistical techniques, serves this purpose (Pallant 2011) by allowing us to test for the unique contribution of the ten characteristics in reducing stress. A stepwise multiple regression analysis was carried out, with the results shown in Table 1. In order to identify the predictive power of each characteristics, the standardized coefficients (beta value), instead of the unstandardized (B value), are presented accompanied by other information such as t-value, R, R squared, and so on.

Only three optimal Mindfulness-Stress regression models were constructed, which reflect the relationships between mindfulness characteristics and quantitative stress, qualitative stress and emotional stress, respectively. None of mindfulness characteristics is the predictor of CP's physical stress, in accordance to their statistical significance. Hence, no regression model was formed for the physical stress and

mindfulness characteristics. Perhaps, mindfulness characteristics are psychological in nature and closely related to CPs' mental symptoms, and are remote to their physical symptoms.

Table 1 Regression Model for Ten Mindfulness Characteristics and three Kinds of Stress

Dependent Variables	Variables	Beta	Sig.	VIF	R square	ΔR square	F(A)	Sig.
1.1 Quantitative stress	Constant	.000			.131	.131	12.346	.001
	Non-judging	.288	.003	1.051				
1.2 Quantitative stress	Constant	.001			.211	.080	10.858	.000
	Non-judging	.308	.003	1.036				
	Trust	.289	.006	1.036				
1.3 Quantitative stress	Constant	.001			.321	.110	12.602	.000
	Non-judging	.311	.001	1.036				
	Trust	.420	.000	1.192				
	Non-reaction	-.356	.001	1.157				
1.4 Quantitative stress	Constant	.001			.357	.036	10.974	.000
	Non-judging	.288	.003	1.051				
	Trust	.475	.000	1.275				
	Non-reaction	-.261	.017	1.405				
	Self-compassion	-.228	.038	1.429				
2.1 Qualitative stress	Constant	.000			.131	.131	12.411	.001
	Attention	.363	.001	1.000				
2.2 Qualitative stress	Constant	.000			.203	.071	10.310	.000
	Attention	.405	.000	1.025				
	Non-reaction	-.271	.009	1.025				
3.1 Emotional stress	Constant	.000			.121	.121	11.245	.001
	Non-judging	-.347	.001	1.000				
3.2 Emotional stress	Constant	.000			.190	.069	9.511	.000
	Non-judging	-.350	.001	1.000				
	Non-striving	.264	.010	1.000				
3.3 Emotional stress	Constant	.000			.233	.043	8.088	.000
	Non-judging	-.402	.000	1.065				
	Non-striving	.242	.016	1.011				
	Description	-.214	.038	1.076				

As indicated in the optimal Mindfulness-Quantitative Stress model, quantitative stress was positively predicted by being non-judging and trust, but negatively predicted by non-reaction and self-compassion, explaining 35.7% of the variance. In the optimal Mindfulness-Qualitative Stress model, qualitative stress was found to be positively predicted by attention, but negatively by non-reaction, accounting for 20.3% of the variance. The optimal Mindfulness-Emotional Stress model demonstrated that emotional stress can be released by non-judging and description, but exacerbated by non-striving, and 23.3% variance was accounted for.

DISCUSSION

Figure 1 illustrates the results of the regression analysis regarding the relationships between the ten mindfulness characteristics and three kinds of stress as experienced by CPs. The results show that seven of the ten characteristics predicted, at least, one stress. The emotional stress can be released by non-judging and description, while quantitative stress is reduced by self-compassion and non-reaction, and qualitative stress is negatively predicted by non-reaction. However, the results also show that emotional stress is exacerbated by non-striving, quantitative stress is increased by trust and non-judging, and qualitative stress rises due to attention. Hence, unlike previous studies for other working population, current research results show that different mindfulness characteristics have different positive and negative impact on the stress of CPs.

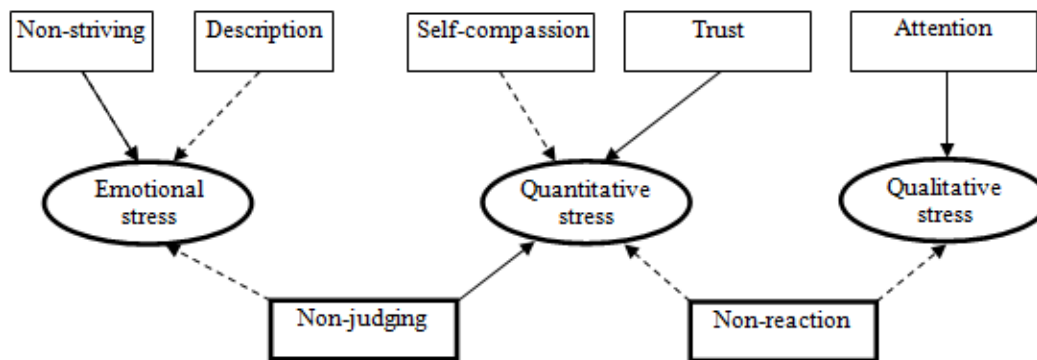


Figure 2 Mindfulness-Stress Model

Note: - - - → significant negative relationship confirmed by regression analysis;
 —→ significant positive relationship confirmed by regression analysis.

Mindfulness Characteristics and Quantitative Stress

As quantitative stress arises from the discrepancy between CPs' expected and actual ability to complete tasks, it will be heavily affected by how they evaluate this gap. Being non-judging may prevent CPs from accurately estimating their quantitative workload. This can increase the magnitude of the discrepancy and ultimately increase quantitative stress. In this study, trust denotes CPs' self-confidence in their ability to finish a job (Schraw and Dennison 1994). However, if a CP is over-confident about his or her productivity, an inappropriate work plan is likely to result (Russo and Schoemaker 1992). The discrepancy between expected and actual ability will therefore increase, because the inappropriate work plan will make it impossible or at least more difficult for the CP to finish the job on time.

The results also indicate that non-reaction and self-compassion can reduce quantitative stress. Non-reaction means that CPs recognize the stress but avoid any instant reaction to it. Recognition of stress is helpful in properly evaluating its source and identifying the discrepancy between expected and actual ability, namely quantitative stress. In addition, non-reaction also prevents CPs from taking instant but ineffective action. These two aspects of non-reaction therefore prevent a further increase in quantitative stress. Self-compassion refers to forgiving, caring for, and loving oneself. This not only allows CPs some freedom from the negative consequences of quantitative stress, but also stimulates improved performance for managing complicated tasks, alleviating stress as a result (Breines and Chen 2012).

Mindfulness Characteristics and Qualitative Stress

Like quantitative stress, qualitative stress results from CPs' perceptions that they lack the competence to complete complex tasks. Therefore, it is also strongly affected by self-perception. As the mechanisms which bring about quantitative and qualitative stress are similar, non-reaction is also helpful in relieving the latter. By taking a nonreactive stance, CPs will be better able to recognize that they are under qualitative stress on the one hand, and can prevent themselves rushing into inefficient action on the other. Attention denotes concentrating on the job when performing a task. Working with attention can sometimes help CPs to enhance their productivity. However, it is not uncommon for CPs to come up against unresolvable problems during the construction process. It was found that paying more attention to these problems will not result in good solutions, but instead increase qualitative stress of CPs.

Mindfulness Characteristics and Emotional Stress

Emotional Stress has been found to be positively predicted by non-striving, but negatively predicted by non-judging and describe. Non-striving indicates CPs has no inclination to strive for any specific goal but accept whatever naturally happened. This passive attitude can prevent CPs from adopting adaptive coping behaviours, such as positive reappraisal and planful problem solving (Bandura 1992), thus exacerbating emotional stress.

Non-judging refers to avoid evaluating things and own thoughts with labels (Baer *et al.* 2004). According to the transactional model (Lazarus and Folkman 1984), stress results from the appraisal of things as threatened and hard to cope. Without judgment of own thoughts and feelings, emotional stress can be prevented. The ability to describe is also helpful for preventing emotional stress, as having this ability would likely result in a greater capacity to distinguish feelings from bodily sensations unrelated to emotional arousal and to understand the complex nature of emotional states (Baer *et al.* 2004).

RECOMMENDATIONS

The results of this study show that the ten mindfulness characteristics exert different influences on stress. Some have no influence on stress at all, some exacerbate it and some release it. Hence, it is recommended that only those mindfulness characteristics that are shown to reduce stress should be facilitated in stress reduction interventions.

As shown above, non-reaction can alleviate both quantitative and qualitative stress. Therefore, it is recommended that CPs should keep calm and avoid acting hastily at work. Responding to stress by taking urgent but ineffective actions may worsen the problem and increase stress levels, given that tasks in a construction project are often complicated and interrelated. In addition to offering CPs MBSR training, construction organizations should also promote the attitude of non-reaction by designing emergency response guidelines through which CPs can learn how to handle complicated problems under great stress (Sime 2007).

The findings also show that self-compassion can facilitate stress reduction for CPs, so it would be worthwhile intentionally fostering this capability. During MBSR training, it will be necessary to encourage CPs practicing self-compassion, as repetitive practice is a way for them to develop this capacity. In addition, construction organizations should also promote the value of self-compassion by advertising its benefits and holding specific training events to teach staff how to develop and use self-compassion.

CONCLUSIONS

It is widely recognized that the majority of CPs suffer from stress at work. Not only does this have negative individual consequences, such as headaches, back pain, and anxiety, but it affects the organization in terms of reduced productivity and increased absenteeism and turnover. Cultivation of mindfulness has been regarded as one effective way to manage stress. However, mindfulness consists of several characteristics, with little so far known about their individual influence on the stress levels of CPs. This study therefore set out to investigate the individual contribution of each mindfulness characteristics to stress reduction among CPs.

Ten major mindfulness characteristics have been identified in this study, as well as their influence on four kinds of stress. The results show that 1) quantitative stress can be relieved by self-compassion and non-reaction, but is increased by trust and being non-judging; 2) qualitative stress is decreased by the adoption of non-reaction but increased by paying more attention to the job; and 3) emotional stress of CPs was exacerbated by non-striving, but released by non-judging and description. Based on these results, a series of practical recommendations are made to enhance instrumental mindfulness characteristics among CPs, including designing emergency response guidelines for fostering non-reaction, and encouraging them to develop the value of self-compassion.

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PERCEPTIONS OF THE RELATIVE IMPORTANCE OF JOB CONTROL AND SUPPORT FACTORS, AS MODERATORS OF WORKPLACE STRESS, AMONG SOUTH AFRICAN CONSTRUCTION PROFESSIONALS: PRELIMINARY FINDINGS

Paul Bowen¹, Peter Edwards² and Keith Cattell³

^{1 and 3}Department of Construction Economics and Management, University of Cape Town, Private Bag, Rondebosch 7701, Cape Town, South Africa

²School of Property, Construction and Project Management, RMIT University, GPO Box 2476, Melbourne 3001, Australia

Occupational stress is moderated by the extent to which workers can control aspects of their work and the type and level of support they receive from colleagues and managers. An ongoing research project explores these factors among professionals working in the South African construction industry. Preliminary findings from descriptive analysis of data from 36 participants show that the five highest ranked job control factors, in terms of perceived importance, are: the volume of project work respondents are engaged in; control over the competence level of other staff engaged on those projects; the flow of work facing respondents; the type of work encountered; and the availability of particular staff (although the latter factor is significantly less important to female professionals). The five highest ranked job support factors, with no significant gender or professional discipline differences, are: adequate compensation (payment); adequacy of co-worker competence; positive job security; supervisor competence; and appropriate career path potential in the employing organisation. Subject to the confirmation of these factors in a later phase of the research project, the implications thereof include: companies wishing to implement effective proactive stress management strategies should look carefully at employee control issues such as how, what, how much and when work is allocated to staff; the composition of work teams should be carefully considered, especially in terms of competence and co-operation; whatever their size, professional firms in the construction industry should develop explicit career path opportunities for employees.

Keywords: construction professionals, workplace stress, job control and support factors.

INTRODUCTION

Background

Psychosocial risk refers to the potential for the psychological or physical well-being of a worker to be harmed as a result of how work is designed and managed within organisational and social contexts (Cox and Griffiths, 2005). The work factors associated with psychosocial risk are: “*excessive workload and work pace, job*

¹ Paul.Bowen@uct.ac.za

uncertainty, inflexible work schedules, irregular, unpredictable or unsocial work hours, poor interpersonal relationships, lack of participation, unclear role in the organisation, poor communication, poor career development, and conflicting demands of work and home” (EU-OSHA, 2014: 5, citing Cox 1993). The impact of psychosocial risks on individual employees can be that both their performance and their health deteriorate. Occupational stress occurs when workers are unable to cope with or control the demands of their work environments (EU-OSHA, 2009). Consequently, the effect of their diminished performance, due to psychosocial risks, manifests as a financial burden to the individuals themselves, as well as to organisations and societies (EC, 2002; EU-OSHA, 2009). The 2014 EU-OSHA review of literature quantifying the cost of work-related stress and psychosocial risks concludes that the financial burden on societies is considerable, costing societies and organisations billions of Euros annually, a finding which establishes a strong business case for the prevention of such risks (EU-OSHA, 2014: 34-7).

Leung, Chan and Cooper (2015) list 46 construction sector work stress studies done over the past 25 years, with various foci. Approximately half of the studies involved construction company employees (workers/labourers – 20%; site managers – 9%; cost estimators/personnel – 20%) and half involved consultants/professionals (engineers – 9%; project managers – 9%; other professionals – 35%). The geographical spread of these is skewed towards Hong Kong (50%), England (15%) and Australia (15%), with only 11% having been undertaken in African countries. Against this background, there is a strong case for more research to be done in the African context. South Africa’s *apartheid* history makes it a case of special interest, given the imbalance in the supply of unskilled and skilled labour and the consequences thereof for stress levels (Leung, Bowen, Liang *et al.*, 2015).

The research reported in this paper was prompted by, and expands, the study of construction industry professionals undertaken by Bowen, Edwards and Lingard (2013). The theoretical framework adopted in that study was based on one of the interactional theories of workplace stress, the JDC-S model, the appropriateness of which was argued in Bowen *et al.* (2013). The scale items used in the research instrument were not identical to Karasek’s Job Content Questionnaire (JCQ) (Karasek, 1985), but were adaptations. Adaptation of the scales was encouraged by Karasek (1985) to deal with the “*situation-specific*” measurement of “*detailed problems that are important in the surveyed work site*” (Karasek, 1985). Although this was probably intended to mean that Karasek (1985’s) JCQ should be broadened, the scale items were replaced with ones deemed more appropriate for the South African construction industry, informed by the literature. The findings of the Bowen *et al.* (2013) research showed strong support for the model. The research instrument used in that study contained nine items in the “*Job Demands*” scale, six in the “*Job Control*” scale, and four in the “*Support at Work*” scale. In the analysis of the data, it emerged that greater complexity in the scales would benefit the interpretation of how control and support factors moderate workplace stress.

The purpose of the current study was therefore to identify the main control and support factors likely to be influential in the design of interventions to moderate workplace stress in the South African construction industry professional sector. The scales used in the Bowen *et al.* (2013) study were expanded substantially, in accordance with the results of a more comprehensive review of the literature. The findings of the current study are an important step towards deepening our

understanding of workplace stress in the South African construction sector, which will, in turn, provide a foundation for the development of appropriate interventions.

According to the Job Demand Control-Support (JDC-S) theory of occupational stress (see Johnson and Hall, 1988), jobs that are high in demands, low in control, and low in workplace social support are experienced as the most stressful and produce the most damaging health impacts (Michie, 2002).

Job demand refers to the stressors involved in accomplishing one's workload, dealing with unexpected tasks, and handling job-related personal conflict (Karasek, 1979, 1985). It can be understood as the perception of the relationship between the amount of mental and physical processing capability or resources available and the amount required by the task (Demerouti, Bakker, Nachreiner *et al.*, 2001).

Job control refers to the employee's degree of control over his or her tasks and conduct during the working day (Karasek, 1979). It can be regarded as a perceived ability to exert some influence over the work environment in order to make it more rewarding and less threatening (Ganster, 1989). Previous studies of occupational stress have shown that lack of job control can be an important cause of strain in various occupations such as nursing and construction (Karasek, 1979; Sauter, Hurrell and Cooper, 1989). Job control concerns the issue of participation in the organization, which can be reflected in whether or not employees feel they have the right to speak freely about matters of concern (Frese, 1987). It also encompasses the balance between levels of authority and responsibility. Tasks associated with low levels of authority and high levels of responsibility deprive employees of the ability to exert influence over their work and the working environment, thereby inducing stress (Schieman and Reid, 2009). Lack of control may also affect relationships with project team members or superiors, the consequences of which (such as arguments with colleagues) can significantly affect stress levels (Leung, Chan and Yu, 2009). Conversely, good interpersonal relationships at work can facilitate good performance (Djebarni, 1996) that, in turn, can help to alleviate stress (Jex, 1998).

Job support refers to being trusted, respected, and supported by colleagues and superiors. Working in such conditions enhances employees' sense of well-being and reduces their stress, which can positively influence commitment and improve job satisfaction (Stenman, Wennström and Abrahamsson, 2010). Those who perceive themselves as having support from their supervisor report more job satisfaction, more emotional commitment to the organization, and less turnover (Taylor, 2008). In addition, job support from both supervisors and colleagues can act as a moderator of stress (Mayo, Sanchez, Pastor *et al.*, 2012).

RESEARCH METHOD AND QUESTIONNAIRE DESIGN

The research instrument

The research is ongoing, and field-administered survey questionnaires are used for primary data collection. Two sections of a multi-sectional instrument, comprising catalogues (see Table 1) for Job Control (19 items) and Job Support (17 items) factors, are reported and analysed in this paper.

Catalogue items were largely drawn from the literature, but were augmented where appropriate with additional items from the researchers' combined knowledge of, and experience in, the construction industry. Additional input was provided by an industrial psychologist. Five-point Likert scale options are given for each catalogue item, to indicate perceived levels of importance, intensity or degree of contribution.

Respondents are also asked to rank the top five items in each catalogue, in terms of their own work experience. Finally, participants are asked to describe a recent work-related stress experience in greater detail.

Administration of the survey

Given the complexity of the survey instrument, it was deemed necessary to meet with respondents to explain the research and the requirements. The first ten completed questionnaires, the completion of which was assisted by the researchers, were treated as a pilot study. These ten respondents were asked to comment on the adequacy of the instrument. No changes were suggested, but they considered the length of the entire multi-sectional instrument to be a problem. Consequently, the researchers decided to meet with all subsequent respondents to explain the research and requirements. Research assistants were engaged to do this.

Purposive convenience sampling was used to identify suitable respondents. This sampling method ensured adequate representation of professional disciplines and both genders. The target frame was restricted to professionals working in the construction industry in the Western Cape province of South Africa, and largely to the metropolitan boundaries of Cape Town. The distribution of the research instruments commenced in February 2012 and is ongoing. Thus far, 36 completed surveys (including the 10 from the pilot study) have been received. The profile of the respondents comprised: 11 architects (7 male, 4 female); 8 project/construction managers (7 male, 1 female); 5 engineers (4 male, 1 female); and 12 quantity surveyors (7 male, 5 female).

ANALYSIS OF THE DATA

The data reported and analysed in this paper are the Job Control and Job Support scales of the questionnaire. The items for these scales are listed in Table 1 below and drawn largely from the work of Sutherland and Davidson (1989), Haynes and Love (2004), Ng, Skitmore and Leung (2005), Leung *et al.* (2009), Leung, Skitmore and Chan (2007), and Love, Edwards and Irani (2010).

Table 1. Catalogue of job control and job support factors as moderators of workplace stress

Item	Job control factors (19-item catalogue)	Job support factors (17-item catalogue)
1.	Flow of work	Co-worker competence
2.	Volume of work	Supervisor competence
3.	Type of work	Co-worker support
4.	Physical environment	Supervisor support
5.	Power to delegate	Co-worker interpersonal skills
6.	Ergonomics	Supervisor interpersonal skills
7.	Decision-making authority	Fairness of criticism from others
8.	Decision latitude	Recognition from others
9.	Staff availability	Freedom to speak openly
10.	Staff competence	Opportunities for skills enhancement
11.	Team size / composition	Positive job security
12.	ICT resources	Adequate compensation (salary)
13.	'Busy-ness' and breaks	Appropriate career path potential
14.	Work travel	Freedom from health issues
15.	Role conflict	Absence of personal / family issues
16.	Forced redeployment	Absence of harassment at work
17.	Forced relocation	Absence of discrimination at work
18.	Forced shift-work	
19.	Forced termination	

Respondents could nominate up to two additional factors in each case, and were asked to rate each factor, on a scale of 1 – 5 (1 = negligible contributor to moderating workplace stress; 5 = major contributor; without other interval definitions). They were also asked to rank, from their own work experiences, the top five factors in terms of frequency encountered (1 = most frequently encountered). In designing the research instrument, it was envisaged that these five would not necessarily match the five highest-rated factors for moderating stress; since, while respondents might regard a particular factor as capable of making a major contribution to stress moderation, they might not have experienced it.

The reliability of the instrument was tested. The Cronbach's alpha for each set of Job Control and Job Support factors is 0.83 and 0.89, respectively, indicating excellent internal consistency in each set. The dataset was subjected to missing value analysis involving the detection of anomalies. No anomalous cases are identified. It is premature to comment on the validity of the instrument, because the intention is to use the ranking exercise to refine the items for use in a future version of the scale, after which we intend to test for construct validity in terms of the JDC-S model.

The Kolmogorov-Smirnov test for normality was applied to the Job Control and Job Support factor data, respectively. For all factors in both categories, values of the statistic were below 0.05 indicating a *violation* of the assumption of normality. Non-parametric techniques were therefore employed to examine differences between groups in terms of gender and professional groupings. Specifically, the Mann-Whitney U Test was used to test for differences in the Job Control and Job Support factor

scores on the basis of gender, and the Kruskal-Wallis H Test was employed to explore differences on the basis of professional grouping.

The five most influential Job Control stress-moderating factors are perceived to be [1] control over the volume of work (less volume=lower stress); [2] control over staff competence (higher levels of competence=lower stress); [3] control over the flow of work (greater control over the flow of work needed to be done=lower stress); [4] control over the type of work (greater control over what work is done=lower stress); and [5] control over staff availability (more abundant competent staff resources=lower stress). The median rating values (*Md*) are reported where appropriate.

With the exception of *staff availability* (males: *Md*=3.00, *n*=24; and females: *Md*=2.00, *n*=11; *U*=74, *z*=-2.11, *p*=0.035, *r*=0.35), there are no significant differences in the perceptions of males and females regarding the impact of the job control factors in moderating workplace stress. Specifically, males, more than females, see greater levels of control over staff resourcing as a meaningful moderator of job stress.

Whilst not significant, the difference in the perceptions of males and females regarding the moderating influence of ergonomics (i.e., control of their working environment in terms of office layout, etc.) is noteworthy (males: *Md*=2.00, *n*=24; and females: *Md*=3.00, *n*=11; *U*=80, *z*=-1.94, *p*=0.053, *r*=0.32). Females, more than males, see this factor as having a moderating influence on stress.

When perception differences are considered on the basis of professional grouping, significant differences exist only in relation to the physical work environment (architects: *n*=11; project and construction managers: *n*=8; engineers: *n*=5; and quantity surveyors: *n*=12), $\chi^2(3, n=36)=9.04, p=0.029$, with medians of 3.00, 3.50, 3.00 and 1.50, respectively; and for forced relocation, $\chi^2(3, n=36)=8.57, p=0.036$, with medians of 1.00, 3.50, 2.00 and 1.00, respectively. With regard to control over the physical environment, it is apparent that, of all professional groups, project and construction managers most see this factor as having the potential to moderate their stress levels; while engineers, albeit to a lesser extent, also hold this viewpoint. Relocating to new projects is always likely to induce some stress for site-based professionals.

Whilst not significant, the difference in the perceptions of the different professional groups regarding the moderating influence of 'type of work' is noteworthy (architects: *n*=11; project and construction managers: *n*=8; engineers: *n*=5; quantity surveyors: *n*=12) $\chi^2(3, n=36)=7.55, p=0.056$, with medians of 3.00, 3.00, 4.00 and 2.00, respectively.

The five most influential Job Support stress-moderating factors are perceived to be [1] adequate compensation (salary) (higher salary=lower stress); [2] co-worker competence (higher levels of co-worker competence=lower stress); [3] positive job security (greater degree of job security=lower stress); [joint-4th] supervisor competence (higher levels of supervisor competence=lower stress); and [joint-4th] appropriate career path potential (greater career path potential=lower stress). There is a clear link between *staff competence* as a job control stress-moderating factor [ranked 2nd] and as a job support stress-moderating factor [ranked 2nd and 4th].

There are no significant differences in the perceptions of males and females regarding the impact of the Job Support factors in moderating workplace stress. However, whilst not significant, the difference in the perceptions of males and females regarding the moderating influence of a lack of harassment at work is noteworthy (males: *Md*=1.00,

$n=24$; females: $Md=2.00$, $n=11$; $U=89$, $z=-1.67$, $p=0.095$, $r=0.28$). Females, more than males, view a lack of harassment at work as a positive moderator upon workplace stress.

There are no differences (significant or noteworthy) in the perceptions of the different professional groups regarding the impact of the Job Support items in moderating workplace stress.

Chi-square tests (χ^2) for independence confirm that the 'marginal' relationships are not significant for: gender and ergonomics, $\chi^2(5, n=35)=8.32$, $p=0.14$; professional group and type of work, $\chi^2(12, n=36)=11.14$, $p=0.52$; and for gender and an absence of harassment at work, $\chi^2(5, n=35)=4.60$, $p=0.47$.

DISCUSSION

The five highest ranked Job Control factors as stress moderators all relate to the work being done and the staff resources available to undertake that work. This confirms the findings of Haynes and Love (2004) and Leung *et al.* (2007) with regard to workload, but highlights the importance of control over type of work and work-flow, as well as over staff availability and competence. Control over staff resourcing is particularly important to males, possibly because of the predominance of men in senior management positions in most construction professional practices (Bowen *et al.*, 2013). Arising anecdotally in the interviews, it may also be that female professionals, as a minority group, exhibit more flexibility and acceptance in terms of team composition.

Control over the physical working environment is particularly important to project and construction managers, and to a lesser extent, to engineers. The reason for this may lie in the nature of the work undertaken by project and construction managers (and engineers), in that some work assignments have the potential to be 'less comfortable' than others e.g., rural or remote site locations for construction projects, or being a resident engineer in a high risk location. Professional architects and quantity surveyors are more likely to be urban office-based. A similar situation pertains to project and construction managers (and engineers) regarding forced relocation. Projects located close to home, family and amenities are bound to be preferable. Control over the nature and location of the working environment is important to project and construction managers (and engineers). The five Job Support factors rated most highly as stress moderators may be grouped into two categories – competence of colleagues (co-workers and supervisors), and career-related issues (salary, job security and career path potential). These results align with those of Leung *et al.* (2007) regarding the negative effects of low levels of reward, and Ng *et al.* (2005) concerning a lack of opportunity to learn new skills in terms of career path development, as well as a lack of autonomy in decision-making.

CONCLUSIONS

The aim of this paper was to present the findings on respondents' ranking of the top five Job Control and Job Support factors. Perceptions of the importance of Job Control and Job Support factors, as moderators of workplace stress, were gathered from construction professionals in South Africa. The highest ranked Job Control factors were found to be: the volume of project work being undertaken; control over the competence level of other staff; the flow of work facing respondents; the type of work encountered; and the availability of staff. The highest ranked Job Support factors were: adequacy of compensation; adequacy of co-worker competence; positive job

security; competency of supervisor; and appropriate career path potential. Significant differences in perception, on the basis of gender and professional groupings, occur only with respect to control of staff resourcing (gender), physical work environment (profession), and involuntary relocation (profession). Firms need to consider 'how, what, how much and when' work is allocated to staff. Work team composition needs careful consideration – particularly in terms of inter-personal relations (important to female staff) and competence. Finally, career path opportunities need to be both motivational and explicit. These are not considered insurmountable challenges in the context of workplace stress and worker health.

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SECURING THE WELL-BEING AND ENGAGEMENT OF CONSTRUCTION WORKERS: AN INITIAL APPRAISAL OF THE EVIDENCE

Nick Bell¹, Colin Powell² and Peter Sykes³

¹Nick Bell Risk Consultancy, 5 Sharpes Way, Bulwark, Chepstow, Gwent, NP16 5TG, UK

^{2 and 3}Cardiff Metropolitan University, Cardiff, South Glamorgan CF5 2YB, UK

Construction sites pose unique challenges for employers who are seeking to develop interventions to improve outcomes for workers. The contractors who constructed the infrastructure for the 2012 Olympic Games were encouraged by the client organisation to actively engage their workers and promote their well-being. This paper examines how scholarly research has approached well-being and engagement in the construction industry. A literature review identified a total of 21 papers that have examined either well-being or engagement in construction and only a single paper examined both subjects. There has been very limited research into this area. The existing papers highlight a number of gaps which could be filled through future research. The concept of well-being in construction is poorly defined and predominantly focuses on stress and work-life balance. There is a lack of clarity or certainty about whether and how some of the recommendations for improving well-being can be realistically implemented in construction, such as giving workers more flexible working arrangements. It is also unclear what specific benefits construction companies, and their clients, could expect to see from engagement or well-being strategies. Consequently, it is currently difficult to make a convincing business case or plan for the introduction of well-being or engagement strategies in construction. Nonetheless, there is evidence that engagement and well-being strategies can improve outcomes for individual construction workers and professionals, such as maintaining or improving health or promoting safety or skills development. Many of the practices that engage individuals also promote well-being: They do not need to be approached as completely separate issues. The extant research suggests that construction companies could usefully review; how they allocate and use resources on projects; the leadership and coaching skills of site managers; how workers can influence the planning of their work, and; their human resources procedures.

Keywords: engagement, safeguarding well-being, well-being.

INTRODUCTION

Engagement is occasionally cited as a technique or tool for improving the working lives of construction workers. For example, during the construction of the infrastructure of the 2012 Olympics, the Olympic Delivery Authority (ODA) “*was committed to encouraging positive engagement with the workforce on all aspects of health, safety and environment*” (Healey and Sugden 2012: 19).

Defining ‘engagement’ is surprisingly difficult: In their report to the UK Government, MacLeod and Clarke (2009) found over 50 definitions in use. Truss *et al.* (2013) describe employee engagement as a ‘contested construct’. Nonetheless,

¹ nick@nickbellrisk.com

Shuck and Wollard (2010) synthesised what they perceive to be a working definition from the existing definitions and theoretical models:

An individual employee's cognitive, emotional, and behavioral state directed toward desired organizational outcomes.

Consequently, MacLeod and Clarke (2009) proposed that engagement improves organisational outcomes by reducing turnover and absenteeism and increasing productivity, innovation, performance and customer service leading to competitive advantages, higher profits, revenue generation and growth.

However, engagement may have beneficial outcomes for individual workers: Engagement is perceived to be one aspect of well-being (Shaufeli 2014). Engagement therefore offers the prospect of improving individual well-being and organisational outcomes (Truss *et al.* 2014).

Well-being was also introduced into the management of the Olympics 'big build' as the ODA required workers to have "*free access to an occupational health service focusing on ill-health prevention and worker well-being.*" (Healey and Sugden 2012: 12). The decision by the ODA to promote both engagement and well-being, and the possible association between these concepts, highlighted by Shaufeli (2014) and Truss *et al.* (2014), suggests that it is worthwhile examining these concepts together.

Well-being is also an unclear construct, although Huppert *et al.* (2009) suggests that it is much broader than simply being engaged or healthy: It includes how someone feels, whether they perceive that have autonomy, are competent and resilient in the face of setbacks and extends to the quality of their relationships and their sense of belonging and contribution to a community.

It is important to understand whether and how the concepts of engagement and well-being can be meaningfully applied in such a socially and physically dynamic environment as a construction project. The workforce is transient (Kines *et al.* 2010) due to the short-term nature of construction projects and high turnover (Mitropoulos and Cupido 2009). Subcontracting adds to this 'churn' and is intrinsically problematic due to the challenges of co-ordinating different, interdependent trades (Kines *et al.* 2010) and the associated potential for conflict and confusion (Cameron *et al.* 2006).

The purpose of this paper is to examine how academic research, undertaken specifically within the construction industry, has defined the concepts of well-being and engagement, what theories are used to explain these concepts, what evidence exists to support particular engagement or well-being strategies and what outcomes have been found for construction workers and construction companies. This paper forms part of a wider Doctoral research project which is investigating associations between worker engagement and health and safety behaviours by workers.

METHODOLOGY

As this study aims to evaluate the extant literature on a subject area, a literature review is an appropriate methodology (Chermack and Passmore 2005). The search strategy, including the relevant exclusion and inclusion criteria, needs to be clearly articulated (Bryman 2012).

Articles were obtained through an interrogation of the Summons 2.0 database. This is a 'federated search' or 'meta search' facility and performs a simultaneous search across a wide range of academic journals and databases, including publishers and providers such as EBSCO, Emerald and PsycINFO. Summon is a web-scale

discovery service and searches have the ability to reveal abstracts from sources that are not ‘content partners’ (Way 2010).

The search was performed in April 2015 and covered all date ranges. Only scholarly and peer-review papers were sought.

A range of search terms were used to identify relevant articles. “*Construction Industry*”, “*Construction Sector*” and “*Construction Worker*” were used in preference to construction: An initial search revealed that ‘construction’ is a commonplace term and returned large numbers of irrelevant results. Wellbeing and wellness were used as variants of well-being. Finally, the term engagement was used by itself. This was to ensure that articles would be returned regardless of whether they addressed job, work or organisational engagement, employee or worker engagement and so on.

These terms were used in different permutations as both ‘all field’ and ‘abstract or title’ searches. The results are shown on Table 1, below. Each column gives two figures. The second figure (in brackets) is the number of results returned when the search terms were only sought in the abstract or title.

Table 1: The Search Strategy and numbers of articles returned

Search term(s) and phrase(s) including Boolean operators	Engagement NOT included as a search term	Engagement IS included as a search term
1. Engagement	N/A	491,623 (71.926)
2. Well-being OR wellbeing OR wellness	486,940 (66,871)	73,368 (1746)
3. “ <i>Construction industry</i> ” OR “ <i>construction sector</i> ” OR “ <i>construction worker</i> ”	48,494 (7,996)	3191 (49)
4. (Search phrase 2) AND (Search phrase 3)	3861 (38)	412(1)

Table 1 shows that a total of 49 articles have specifically investigated some aspect of engagement within the construction industry or in relation to construction workers. 38 articles have specifically examined well-being in this sector. Only a single article has specifically addressed engagement and well-being in the construction industry.

This gave a total of 88 discrete articles. There were read in full and were included if they specifically addressed how well-being or engagement influenced outcomes of individuals working within the construction industry (for example influencing their health or behaviours). Therefore articles which examined well-being of communities or building occupants, or examined stakeholder engagement, were rejected. One paper was rejected as it was a study protocol.

In total there were 8 relevant articles that addressed engagement in construction, 13 papers that addressed well-being in construction, and 1 paper that addressed both. This created a total of 22 papers which are the subject of this literature review.

WELL-BEING IN CONSTRUCTION

Theories of Well-Being

Only a single paper (Mostert *et al.* 2011) used both the terms well-being and engagement within the abstract or title. This suggests that there are different explanations, other than engagement, for how well-being can be defined and promoted. Toor and Ofori (2009: 301) is the only study to provide an overview of well-being literature to explain what they actually mean by well-being. Their

definition is broadly aligned to the framework proposed by Huppert *et al.* (2009): “People’s feelings about themselves, their family, work and social environment”.

The Job Demand Control–Support theory is a popular theory for explaining stress (used by Bowen *et al.* 2013 and 2014, Meliá and Becerril 2007). The remaining nine papers measure associations between phenomenon without an overt, underpinning theory or framework.

Only one study (Broadbent and Papadopoulos 2014) is based on an intervention: These authors examined delegate responses to a suicide prevention programme amongst young men in the Australian construction industry. Two papers measured occupational exposures to health impairing agents: Sleep deprivation and noise (Fernández *et al.* 2009, Powell and Copping 2010). The other papers are based on surveys, interviews and literature reviews.

At present, there is no academic research investigating the impact and practical challenges of introducing a well-being intervention into a construction company or to a construction site. Researchers should also consider explaining what they mean by 'well-being', particularly for a very practical industry like construction.

Defining Well-Being in Construction

In the absence of a clear definitions of well-being, it is necessary to infer what researchers mean by 'well-being' based on the particular focus of their study.

Stress is as an indicator or measure of well-being in five of the fourteen papers. Job satisfaction, emotional exhaustion or mental health are presented as other indicators of psychological well-being (Broadbent and Papadopoulos 2014, Zacher *et al.* 2014).

However, there is a recognition that well-being has physical components as well (Francis and Lingard 2012, Broadbent and Papadopoulos 2014, Sang *et al.* 2007). Some papers go further and only examine well-being in terms of physical injuries, illness or fitness, such as hearing loss (Choi 2009, Fernández *et al.* 2009).

Well-being is used as a measure of both illness and/or wellness. For example, it is possible to measure the factors that damage psychological or physical health and to therefore focus on illness and illness prevention (Meliá and Becerril 2007, Bowen *et al.* 2014, Fernández *et al.* 2009).

In contrast, Mostert *et al.* (2011) perceived burnout to be a consequence of low worker well-being (due to negative work-home interference), and engagement as a result of high worker well-being (caused by positive work-home interference). Therefore, well-being can be enhanced, not just protected (Choi 2009, Toor and Ofori 2009).

It is possible to examine the well-being of construction workers (Choi 2009), or professionals, such as architects (Bowen *et al.*, Sang *et al.* 2007, Toor and Ofori 2009) or both (Francis and Lingard 2012, Meliá and Becerril 2007, Powell and Copping 2010, Zacher *et al.* 2014). Zacher *et al.* (2014) found no differences in their own study on well-being outcomes for blue and white collar workers.

Finally, well-being studies have focussed on occupational or domestic factors that influence well-being, or the interplay between the two. For example, a study into occupational noise exposure (Fernández *et al.* 2009) only examined occupational noise exposure, and not voluntary noise exposure at home. In contrast, work-home conflict is viewed as a factor that influences (or is a measure of) well-being (Bowen *et al.* 2014, Francis and Lingard 2012, Sang *et al.* 2007, Zacher *et al.* 2014,)

Collectively, these studies present well-being as a measure of mental and physical fitness of construction workers and professionals, including their satisfaction and engagement (highlighting the value of examining these concepts together), and it is influenced by their control over occupational and domestic factors. This is a narrower perception of well-being compared to the definition of Huppert *et al.* (2009). For example, the studies of well-being in construction do not cover perceptions of competence, altruism and a sense of belonging to a wider community. Construction companies might increase workers' perceptions of well-being by enhancing their skills or encouraging voluntary work in the community (e.g. offering paid leave for volunteers). This has not been investigated in the eligible studies.

Organisational outcomes of Low well-being

The well-being studies largely focus on and measure individual well-being outcomes, such as stress. Only Meliá and Becerril (2007), Sang *et al.* (2007) and Powell and Copping (2010) measured individual outcomes of worker well-being which would be relevant to their organisation such as intentions to quit, changes to work performance or changes in accident rates. The remaining papers rely on previous studies to provide evidence of the impact of poor worker well-being on organisations or the wider industry (such as professionals leaving to work in other sectors) or simply infer what the organisational consequences may be, such as sickness absenteeism of site managers (Choi 2009, Davidson and Sutherland 1992, Fernández *et al.* 2009, Francis and Lingard 2012, Morrison and Thurnell 2012, Zacher *et al.* 2014).

There has been no investigation of the effect of well-being strategies at the project-level, such as lost production days or the achievement of zero defects at handover (a measure of work quality in construction). Addressing these gaps would help to establish whether there is a business case for introducing well-being interventions.

Improving or safeguarding well-being

The well-being papers sometimes offer practical guidance for employers. For example, making care costs a salary packaged benefit to offer tax benefits, offering a flexible package of benefits for employees to choose from (e.g. flexible working arrangements, reduced working hours, social activities and fitness) and offering emotional support and practical advice through employee assistance programmes (Francis and Lingard 2012, Morrison and Thurnell 2012, Mostert *et al.* 2011). These procedures would normally be managed by human resources departments. It is unclear how measures such as flexible working arrangements, or reducing the endemic problem of long working hours in construction (Bowen *et al.* 2014), could be implemented in construction. It might be achieved, for example, by encouraging and facilitating 'multi-skilling' amongst trade staff to give a pool of resources that could be drawn upon to give greater flexibility. Allocating sufficient workers to a project could enable work to be done in shifts rather than working long hours.

A supportive organisational culture is required to initiate these changes (Francis and Lingard 2012, Morrison and Thurnell 2012). This includes minimising a competitive workplace culture (Bowen *et al.* 2014) perhaps by providing adequate material resources (Zacher *et al.* 2014). Fostering supportive leadership and co-worker support is important and could be promoted by encouraging positive social interactions and training managers (Bowen *et al.* 2014, Meliá and Becerril 2007, Zacher *et al.* 2014).

While Francis and Lingard (2012) recognise that well-being initiatives need to be driven from the 'top down' none of the well-being or engagement papers highlight the

role of the client in improving the lives of construction workers and professionals. Ultimately clients pay for these project, select contractors and consultants and approve or challenge proposed timescales. It would be helpful to provide guidance to clients on how and why they should be supporting well-being and engagement strategies.

The research suggests that good project management skills, including the allocation of sufficient resources, are critical to promoting well-being in construction. Resources include supportive managers. Staff may then feel supported and have reasonable working hours and conditions. It may lead to flexible working arrangements and chances to volunteer. Opportunities to develop worker's skills should be explored.

ENGAGEMENT IN CONSTRUCTION

Overview of engagement studies

One paper (Mostert *et al.* 2011) addresses both engagement and well-being. It is notable that engagement is investigated in relation to safety in five papers (rather than quality, for example). Another theme (in four papers) is the association between engagement and improved learning outcomes for delegates. Three papers were based on interventions (Cameron and Duff 2007, Williams *et al.* 2010, Oude Hengel *et al.* 2012). The remaining papers are based on surveys, interviews and literature reviews.

Definition and consequences of engagement

Engagement is described in a number of ways. Cameron and Duff (2007) appear to equate engagement with toolbox talks, induction, recognition of safe working practices, use of safety committees, including safety in working practices (the term is not explicitly defined, however). Therefore, engagement can be conceptualised as the process of communicating and consulting with workers.

However, engagement can also describe how people feel and think, which might influence how they go on to behave (Conchie *et al.* 2013). Engagement can therefore describe how well someone commits themselves mentally or emotionally to their work or an activity, such as a learning opportunity (Albert and Hallowel 2013, Demerouti *et al.* 2010, Mostert *et al.* 2011).

The papers largely focus on individual consequences. Wang *et al.* (2008) refers to a cost-benefit analysis highlighting advantages of craft training. No papers had similar analyses relating to engagement. It may be inferred that low engagement will increase turnover and absenteeism due to negative attitudes, fatigue and burnout (Conchie *et al.* 2013, Mostert *et al.* 2011) or could contribute to accidents (Williams *et al.* 2010).

The job demands-resources model proposes that high levels of resources promotes personal growth and development, as well as engagement (Mostert *et al.* 2011). None of the studies (either relating to well-being or engagement) specifically measure associations between workers' perceptions of their own competence and their sense of engagement or well-being: This could be an interesting area for future research.

Consequently, like well-being, engagement appears to be perceived in a number of ways. Engagement can be seen as either something we do to workers (e.g. how we involve them) or how they respond in terms of their thoughts, feelings and behaviours.

Practices which engage workers and explanatory theories

According to the job demands-resources model, individuals become engaged when these have sufficient resources (including appropriate training) to perform their roles and when they have adequate support from supervisors and co-workers (Conchie *et al.*

2013, Mostert *et al.* 2011, Williams *et al.* 2010). In common with well-being, engagement is contingent upon support from others and having adequate resources.

To promote a sense of support in construction, supervisor forums could allow issues to be raised and best practice to be shared and different trades could be brought together on site to improve communication and co-operation (Conchie *et al.* 2013).

Performance feedback is one sort of job resource which promotes engagement (Conchie *et al.* 2013, Mostert *et al.* 2011). Engagement is enhanced when workers are given ownership of and a sense of control over their work and working arrangements (Conchie *et al.* 2013, Kulchartchai and Hadikusumo 2010, Mostert *et al.* 2011).

Cameron and Duff (2007) found that performance can be raised through goal-setting, monitoring and feedback. While this approach may not seem 'engaging', goals were set collaboratively and were supported by an action plan allocating responsibilities and resources to support those goals. It is therefore possible that the demands were seen positively, managers felt involved and valued, and considered the resources to be adequate. Consequently, even a very task-oriented industry, like construction, can take a 'softer' approach to managing projects and their workforce, although managers would need to be selected and trained to adopt these skills and involve workers.

Providing workers with opportunities to learn and use a variety of skills promotes engagement (Conchie *et al.* 2013, Mostert *et al.* 2011), although the strength of this association is unclear. Training providers might use a hands-on, participatory approach, drawing on and valuing the experience of workers (Albert and Hallowel 2013, Williams *et al.* 2010). Williams *et al.* (2010) found that participatory, peer-led training led to behavioural changes, perhaps due to improved engagement with the material. In contrast, Oude Hengel *et al.* (2012) speculated that problems with the delivery of training accounted, in part, for their finding that physical therapy and empowerment training had no effect on worker engagement or social support. Formal training is only one way to develop construction workers: On-site mentoring and coaching are valuable approaches (Wang *et al.* 2008) and these skills could be taught to site managers to improve how they develop and support workers.

It is notable that engagement and well-being both appear to be promoted by ensuring that adequate resources are available, giving workers control over their work and working arrangements and helping individuals to feel supported by co-workers and managers. Well-being and engagement are both considered to influence, or are a measure of, worker's thoughts, feelings and perceptions. Such overlaps are to be expected given the view that engagement is simply one element of well-being (Huppert *et al.* 2009, Schaufelli 2014). A key difference between the concepts is that well-being includes aspects of physical health. Theoretical models suggest that a link exists between feeling competent and feeling engaged and well. This was not covered in the eligible studies and may be worthy of further investigation.

CONCLUSIONS

Efforts to promote well-being and engagement during the Olympics big build, and the theoretical association between the concepts, suggested that it may be worthwhile examining the concepts together. Only 22 papers have specifically examined how engagement and well-being strategies in construction influence outcomes for people working in the sector. Nonetheless, these highlight gaps in extant research and indicate what companies might do to promote both well-being and engagement.

In terms of a research agenda, the research community would benefit from defining what well-being means in the context of construction: The conceptual framework proposed by Huppert *et al.* (2009) suggests that there is more to this construct than simply preventing stress or achieving a good work-life balance. It would be useful to build on the work of Oude Hengel *et al.* (2012) to develop interventions and examine the practical challenges (and benefits) of applying well-being and engagement strategies in construction. It would be helpful to identify what impact these have on clients, as ultimately they can help to drive these initiatives through their supply chain.

The concept of engagement has been examined in relation to safety performance in five papers. This current paper forms part of a wider research project to evaluate whether engaging workers is an effective means of improving safety in construction.

It is worth noting that studies investigating well-being and engagement in construction have been drawn towards the Job Demand Control–Support theory or Job Resources-Demands model. It may reflect the pragmatic nature of the industry that research in this sector use explanatory models that contrast demands with resources. Future research might investigate the utility of other theoretical models in construction.

There are a range of practical measures for improving well-being and engagement. Managers need to be trained in effective leadership skills (enabling them to involve, coach and support workers and manage the relationships within their team). Project management skills and support are needed to ensure that sufficient resources are allocated to projects and used effectively. Workers should be offered (and will be engaged by) a blend of participatory training, mentoring and coaching and the ensuing sense of competence is a measure of well-being. There is also a need for a range of human resources procedures around flexible working arrangements, employee assistance programmes and other formal mechanisms to support workers.

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IDENTIFICATION OF DEMAND AND RESOURCE TYPOLOGIES WITHIN A SYSTEMS FRAMEWORK

Michelle Turner¹ and Helen Lingard

School of Property, Construction and Project Management, RMIT University, Melbourne, Victoria, Australia

Work-life fit occurs when people have the resources required to meet demands such that role performance (both at work and in non-work life domains) is effective. Models of work-life fit emphasise the interactive nature of demands and resources, however previous research has treated these as entirely independent of one another. This research makes a new conceptual contribution to an area in which theory is under-developed, by adopting a systems approach to understanding the dynamic interactions between demands and resources. Interviews were conducted with 59 construction workers based in Melbourne, Australia to explore how demands and resources were experienced by workers. Using a systems framework, data were analysed using thematic analysis. Results identified two demand typologies associated with demand-to-demand interaction, which challenges previous research claiming that resources are exclusively required to meet demands. Demands operating as ‘influencers’ have a major impact on the conditions of the interdependent demand, while demands operating as ‘creators’ generate a new demand and shape the conditions of that demand. One resource typology related to resource-demand interaction was identified. ‘Enabling resources’ enable an individual to manage multiple demands across multiple domains, and may also enable an individual to manage multiple demands within a single domain. Findings suggest that treating demands and resources as unrelated is not helpful. A lack of fit is damaging for the individual, therefore it is useful to know that demands and resources are interdependent and these interdependencies will vary according to individuals. Using a systems approach to understanding demands and resources will be helpful to organizations seeking to support workers to achieve optimal work-life fit.

Keywords: demands, systems framework, resources, wellbeing, work-life fit.

INTRODUCTION

Work-life fit occurs when an individual perceives that they have the resources required to meet demands such that role performance in both work and non-work roles is effective (Voydanoff, 2007). Work-life fit is important for satisfactory well-being (Edwards and Rothbard, 2006; Voydanoff, 2007). The application of a systems approach to work-life fit supports Kanter’s (1977) critical research on work and family, where she referred to the myth between the separate worlds of work and family life. That is, one domain does not exist independently of the other domain. Rather, the domains are fundamentally linked. The recognition of the interdependence between domains has led researchers to recognize the dynamic rather than static nature of these relationships. The dynamic nature of the interactions between work and non-work life highlights a critical point in that theory development must consider the whole and the interrelation between the parts.

¹ michelle.turner@rmit.edu.au

Recent research in the construction industry investigated the interaction between demands and resources and explored the different configurations constituting work-life fit for workers (Turner, 2012). The research was conducted over three interdependent stages. The first stage entailed identifying and defining a complete and validated set of demands and resources applicable to workers in the Australian construction industry (Turner and Lingard, 2014). The second stage used the set of demands and resources to quantitatively measure and map the demand and resource configurations of workers and explore what constitutes work-life fit for different groups of workers (Turner, 2012). The third stage comprised of interviews with participants to provide context around their configuration of work-life fit. This paper reports on stage three of the research.

AIM

The research seeks to explore how demands and resources actually interact within a dynamic system for workers of the Australian construction industry. The findings of this research contribute to conceptual models of work-life fit by demonstrating how demands and resources can interact within and across domains, such that the conditions and meanings of demands are influenced, altered or minimised.

LITERATURE REVIEW

Work-life fit

Work-life fit occurs when the individual perceives that they have the resources required to meet demands such that role performance is effective (Voydanoff, 2007). Models identified by Teng and Pitman (1996), DeBord *et al.* (2000), and Brennan *et al.* (2007) emphasise the interactive nature of demands and resources within a work-life fit framework. Demands and resources originate from multiple domains, including work, family and community. Misfit occurs when demands exceed resources, and this is damaging for the individual as lack of fit can result in strain and illness (Edwards and Rothbard, 2006; Voydanoff, 2007).

The ecological systems framework (Bronfenbrenner, 1979) has been applied to the work-life fit model. This model considers each of the domains as a microsystem which is inter-connected with other domains (microsystems). The experience of a demand in one microsystem can be influenced and shaped by the experience of a demand or resource in another microsystem. In considering the experience of demands, it is imperative that the complex nature of interactions between microsystems is considered (Pocock *et al.*, 2012; Voydanoff, 2007). Various conceptual models of work-life fit have acknowledged the dynamic process in which individual's demands and resources will change in response to changes in work, home and community demands and resources (Barnett, 1998; DeBord *et al.*, 2000; Teng and Pittman, 1996; Voydanoff, 2007).

Demands

A consistent definition of demands has not been applied within the work-life literature. Definitions often reflect role overload, which is based on having a negative response to work pressures (Boyar *et al.*, 2008), do not consider demands arising from other domains such as family or community, and assume that demands are exclusively negative experiences (Boyar *et al.*, 2007). Furthermore, the work role is often treated as a required and negative demand, whereas the family role (though family is a

required demand) is often considered to be the preferred context in which people want to focus their energy (Grawitch, *et al.*, 2010).

Some researchers have acknowledged the breadth of demands and have developed definitions which cover the various facets of demands. Edwards and Rothbard (1999, p.88) position demands within a person-environment fit framework, defined as “*qualitative and quantitative requirements faced by the person and include objective demands (e.g., commute time, length of work week) and socially constructed norms and role expectations*”. Poelmans, *et al.*'s (2003) definition of demands is similar to definitions applied by Bakker *et al.* (2005) and Edwards and Rothbard (1999) as it identifies the multiple components of demands. Poelmans *et al.* (2003, p.277) contend that “*demands can require the expenditure of time and exertion of effort, but they can also require that the individual experiences some condition or situation that does not in itself require time expenditure or effort, but represents a ‘psychological’ demand*”. Bakker, *et al.* (2005, p.170) refer to work demands as “*physical, social, or organizational aspects of the job that require sustained physical or mental effort and are therefore associated with certain physiological and psychological costs*”. While Bakker *et al.* (2005) focus their attention on work demands, this definition is transferrable to other domains such as family and community

Resources

Like demands, the resources concept lacks a common definition from which to progress and extend theory. Some studies refer to resources but do not explicitly provide a definition (for example, Pitt-Catsouphes, *et al.*, 2007). Other studies refer to interventions, strategies and initiatives which are types of resources, however they are not explicitly referred to as resources. In recognising the substantial scope of resources, more comprehensive definitions have been developed. Poelmans *et al.* (2003, p.277) refer to resources as being “*both internal/psychological and external/situational to the individual. An internal resource might be an internal locus of control that drives a person to cope with a work or family stressor, whereas an external resource could be a grandparent willing to baby-sit during the day*”. Greenhaus and Powell (2006) frame resources within a positive work-family spillover construct, defined as “*an asset that may be drawn on when needed to solve a problem or cope with a challenging situation*” (p.80). Dolcos and Daley (2009, p. 294) outline a comprehensive definition of work resources, as “*physical, psychological, social, or organizational aspects of the job that*”: (a) reduce job demands and the associated physiological and psychological costs; (b) are functional in achieving work goals; and (c) stimulate personal growth, learning, and development. While Dolcos and Daley (2009) focus their attention on work resources, this definition is transferrable to other domains, such as family and community, and provides a sound basis for identifying a wide range of resources across domains. Furthermore, the definition explicitly states that resources are a means of meeting demands, which is relevant to the work-lift fit framework embedded within a demands-resources framework.

Construction industry

Workers of the Australian construction industry experience a range of demands including long working hours, overtime hours, and weekend work (Turner, 2012). These demands have been linked to work-family conflict (Lingard, Francis and Turner, 2010a). The experience of work-family conflict by Australian construction workers is of concern as conflict is associated with negative outcomes for the worker and the organization. Conflict between work and family life has been associated with

lower levels of life satisfaction (Lambert, et al., 2006), job satisfaction (Kinnunen, et al., 2004) and organizational commitment (Thompson, et al., 1999) as well as higher levels of turnover intention (Karatepe and Kilic, 2007) and job withdrawal behaviours, such as absenteeism and tardiness (Mesmer-Magnus and Viswewvaran, 2006). Workers in the construction industry also experience a range of resources such as supervisor support, flexibility and work schedule control (Lingard, Francis and Turner, 2010b; Turner, 2012). It is not well understood, however, how these demands and resources interact to support workers' work-life fit.

METHODOLOGY

The data collection phases preceding the interviews are briefly explained so as to provide context for the findings reported in this paper. Initially, participants were asked to score demands according to the extent they were experienced, from (1) no extent at all, to (7) very large extent. A total of 43 demands were considered by participants consisting of 18 work demands, 12 family demands, nine community demands, and four personal demands. An example of a work demand is 'work overload', described as 'not enough time to complete your assigned work duties. You work hard over a period of time to maintain a work load that you consider excessive'. Following the scoring of demands, participants were asked to indicate which resources would be most important in helping them to meet their demands scored as (5) considerable extent, (6) large extent, and (7) very large extent. A total of 69 resources were considered by participants, consisting of 25 work resources, 24 family resources, 18 community resources, and two personal resources. An example of a family resource is 'partner emotional support', described as 'the concern, care, trust and empathy from your partner to help you respond to your demands'. Demands and resources were derived from the literature, and are reported in Turner and Lingard (2014).

Interviews were conducted with participants to explore their work-life fit configuration, reflected by their experience of demand and resource requirements from the work, family and community domains. Firstly, participants were asked questions about their experience of demands which had been given especially high or low rankings, and what implications those demands had in the context of their overall experience. Secondly, participants were asked how resources could assist them to meet the demands they experience. Thirdly, participants were invited to make additional comments about demands and resources. Thematic analysis was applied to interview transcripts.

RESULTS

Sample

Interviews were conducted with fifty-nine participants of the Australian construction workforce. Participants were recruited from two participating organisations that were both medium sized contract-based construction organizations based in Australia. The head office of the two organizations was located in the city of Melbourne, and both large-scale commercial and residential projects were undertaken across the country. Given that the research sought to explore workers' experience of demands and resources in the Australian construction industry, the data from organization one and two were combined in order to broaden the sample. Furthermore, the unit of analysis was at the individual level rather than at the organizational level, therefore combining

the data sets was warranted. The demographic characteristics of the sample are summarised in Table 1.

Table 1: Demographic characteristics of the sample

	N	%		N	%
<i>Gender</i>			<i>Parental status</i>		
Male	44	74.6	Children	30	50.8
Female	15	25.4	No children	29	49.2
<i>Household Status</i>			<i>Type of pay</i>		
Live alone	8	13.6	Salaried	47	79.7
Live with partner	9	15.3	Waged	12	20.3
Live with partner and children	27	45.8	<i>Work location</i>		
Live with parents	8	13.6	On site in direct construction	13	22.0
Live with friends or housemates	7	11.9	Onsite in site office	28	47.5
			Head office	18	30.5

The mean age of participants was 35.49 years (SD = 10.18 years). The average weekly work time of participants was 54.27 hours (SD = 8.66 hours), the average weekly travel time was 6.72 hours (SD = 3.64 hours), and the average time spent on household chores was 7.19 hours (SD = 4.45 hours).

Demand-to-demand interaction

Two demand typologies emerged from thematic analysis of the interview data. Demands which operate as ‘influencers’ have a major impact on the conditions of the interdependent demand, and it is suggested that if the conditions of the influencing demand change, so too will the conditions of the interdependent demand. In contrast, demands which operate as ‘creators’ generate a new demand and shape the conditions of that demand. It is suggested that if the ‘creator’ is altered or removed, then the resultant demand will also be removed.

A demand-to-demand interaction emerged between project characteristics, work overload, and mental and physical strain. Participants experienced emotional and mental strain at work driven largely by long working hours, tight deadlines, and the unplanned nature of projects. Many participants reported that strain at work was often linked to project characteristics and in particular, the unpredictable nature of projects. A male participant living alone commented that: “*project characteristics has an impact on timelines, and things seem to be moving faster now compared to ten years ago*”. Another male participant living with his wife and children explained that: “*in projects, things change. They can be unpredictable, with lots of unplanned activities*”. The unpredictable nature of projects led to time management issues for some participants. Participants reported that they were unable to complete their daily planned activities as unplanned activities often had to take precedence and be dealt with immediately, which added to an already high workload. A female participant living with her parents commented: “*work is often reactive, and when an emergency arises it must be dealt with now*”. Similarly, a male participant living alone explained that: “*crisis rectification and crisis resolution leads to emotional strain.... things change regularly, hourly, daily. My job can be very reactive which is stressful*”.

Participants acknowledged that the construction industry was largely project-based and this impacted upon the demands experienced at work. In addition to this,

participants explained that some project tasks required long hours to meet a tight deadline. In these instances pressure was high as there could be a financial penalty for the contracting organisation if the deadline was not met.

Figure 1 shows the interaction between work demands, using a scenario described by participants. In this scenario, work overload is influenced by project characteristics, particularly when factors such as program changes, program acceleration, and unplanned activities occurred. Consequently, work overload creates mental strain and emotional strain for workers. The semi-permeable shape of each demand indicates that one demand interacts with another demand through a permeable boundary. The concept of a permeable boundary is applied to the work-life fit model, which considers that each demand experienced by an individual does not occur in isolation from other demands.

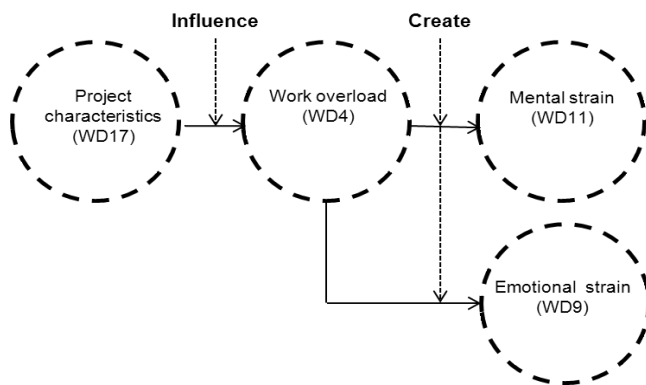


Figure 1. Example of a demand-to-demand interaction within the work microsystem which results in the creation of strain-based demands. Note that WD refers to work demand. The number (for example, WD1) represents the unique code allocated to each demand and resource, as outlined in Turner and Lingard (2014).

Another demand-to-demand interaction emerged in the work microsystem, whereby the construction industry’s expectation of long and irregular work hours had an influence upon organizational expectations of work hours. Organizational expectations then created a long work hours culture. Long work hours then influenced the likelihood of overtime hours. This interaction is shown in Figure 2. A male participant living with his parents commented: “industry and organizational expectations drive big hours, overtime and weekend work. But this organization is no different to other construction organizations”. Another male participant living with friends explained: “hours and volume of work are associated with this industry. You receive no sympathy from other construction organisations”. Similarly, another male participant living with his wife and children commented: “the norm is six to seven working days per week in this business. It’s deadline driven, that’s the industry norm”.

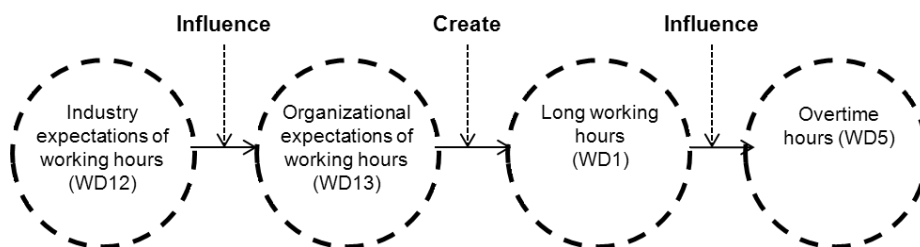


Figure 2. Example of a demand-to-demand interaction within the work microsystem.

Resource-to-demand interaction

One resource typology related to resource-to-demand interaction emerged through thematic analysis. Enabling resources are defined as those resources which ‘enable’ an individual to manage multiple demands across multiple domains.

A resource-to-demand interaction emerged between work and family demands and resources as shown in Figure 3. In this Figure, partner practical support enables individuals to participate in long work hours and overtime hours. Furthermore, partner practical support enables these workers to manage their child-based demands.

Participants with dependent-aged children indicated that they were not the primary care giver, and relied heavily on their partner for assuming child care responsibilities. A male participant living with his wife and children explained that: *“my partner is able to look after the house, child and pets”*. Another male participant living with his wife and children commented: *“my spouse has flexibility with her job with start and finish times, plus works part time. This allows my home based demands to be met. If there was a combination of two roles like mine, I couldn’t meet my demands”*. Similarly, another male participant living with his wife and three young children explained: *“my wife is a great support. She used to work part time, at the moment she doesn’t work. She looks after the kids”*.

Many participants also indicated that their partner took the lead on household chores. One male participant living with his wife and child commented: *“my partner does the washing throughout the week so it doesn’t build up”*. Another male participant living with his wife and children commented that: *“my wife does all house work”*.

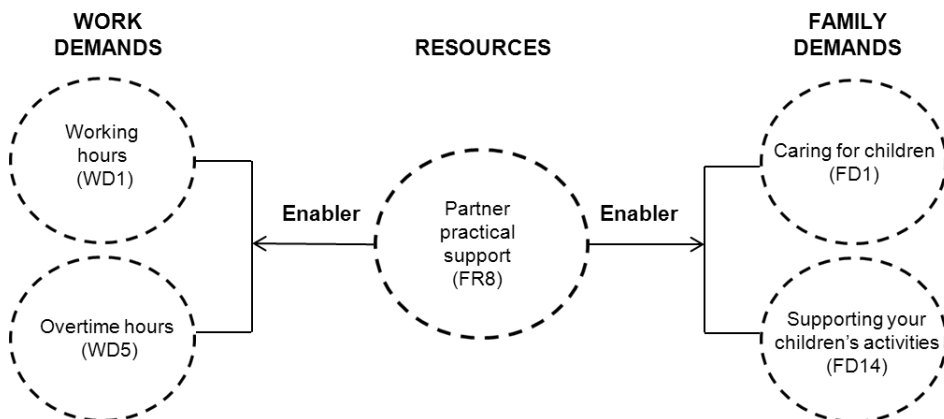


Figure 3. Example of a resource-to-demand interaction in which partner practical support enables work and family demands to be achieved. Note that WD refers to work demand, FD refers to family demand, and FR refers to family resource.

DISCUSSION

The research adopted a systems approach to understanding the dynamic interactions between demands and resources experienced by workers of the Australian construction industry. Findings support the notion that theory development must consider the whole and the interrelation between the parts of the work, family, and community system. In seeking to explore and define the range of demands that operate within and between each microsystem, it is imperative to consider which demands have an interdependent relationship with other demands, as well as considering the impact that resources have on meeting demands. Pocock *et al.* (2012) developed a conceptual model which contends that the work, family and community domains, as well as the domain intersections, create demands and resources. Findings of this

research extend the work of Pocock *et al.* (2012) by identifying some of the demand-to-demand interactions demonstrated within the Australian construction industry. Within a microsystem, some demands may act as 'influencers' and some may act as 'creators'. This means that a demand should not be considered in isolation. Instead, the demand should be considered as one part of a dynamic and interactive system.

The research extends the work-life fit model which applies a demand-resource approach by challenging the notion that resources are exclusively required to meet demands such that role performance is effective. By applying a systems approach, it is possible that a demand can be managed in a number of different ways. Firstly, a resource may be utilised to assist in managing a demand (resource-to-demand interaction). Alternatively, the conditions of a demand may be altered, so that the interdependent demand is perceived as manageable (demand-to-demand interaction). The complex nature in which demands function within a system adds to the body of knowledge and progresses the work-life fit concept.

Findings of this research suggest that one demand can interact with another demand through a permeable boundary. By applying boundary theory (Ashforth, *et al.*, 2000) to the findings, it is probable that when the boundaries between the work and non-work microsystems are sufficiently permeable and flexible, processes occur through which aspects of the various domains influence each other. The concept of a permeable boundary is applied to the work-life fit model, which considers that each demand experienced by an individual does not occur in isolation from other demands and/or resources. Within a system, demands are inherently connected. This connection results in an interaction, in which the conditions of one or both of the demands are altered due to their interdependent relationship.

An understanding of the work domain as a dynamic and interactive microsystem is an important consideration for construction organizations seeking to create a productive and positive work environment for their workers. In this context, an understanding of the interdependent nature of demands within the work domain is important so as to manage demands and support workers. Organizations which seek to minimise or remove demands perceived as damaging should focus on modifying those demands (such as work overload), which are creating the damaging demands (such as emotional and mental strain). Through the application of a systems approach, organizations have the capacity to treat the cause of damaging demands, thereby alleviating the symptoms, rather than merely treating the symptoms which are likely to re-emerge and cause harm to workers.

CONCLUSIONS

The research has important implications for progressing the work-life fit model using a demands and resources approach. The findings identified the interactive nature of demands and resources within and across microsystems. The research also has important implications for construction organizations seeking to support the work-life fit of their workers. In particular, focusing on those demands perceived as harmful and understanding the interdependent nature of these demands. A limitation of the research is the sample used. Participants came from two medium-sized construction organizations based in Melbourne, Australia. Therefore, the results cannot be generalised to other cities within Australia, nor other countries. Furthermore, the construction industry is comprised of large, medium and small construction organisations. Given that the participants of the research worked for medium-sized construction organizations, results cannot be generalised to small and large

construction organizations. Additionally, the construction industry is made up of both commercial and domestic sectors. Within the commercial sector, work is differentiated between building and civil engineering projects. This research investigated workers experience within the commercial building sector, therefore results cannot be generalised to other industry sectors. Additional research is required to explore demand-resource interactions in organizations of different sizes, locations, and sectors.

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MANAGING THE UNKNOWN – THE HEALTH RISKS OF NANOMATERIALS IN THE BUILT ENVIRONMENT

Wendy Jones¹, Alistair Gibb, Chris Goodier and Phil Bust

School of Civil and Building Engineering, Loughborough University, Loughborough, Leicestershire, UK

The application of nanomaterials, containing particles 1000 times smaller than the thickness of a human hair, is increasing but uncertainties persist regarding their potential health effects. An ongoing study to identify where nanomaterials are used in construction and to assess the impact of demolition processes on particle release has identified difficulties which arise when dealing with the unknown: assessing, and managing the risks of these, and other, new materials. The widespread use of materials whose risks are inadequately understood is clearly unsatisfactory. However, the timing of a detailed health evaluation for a new product or process is not straightforward - a focus on these aspects too early in a developmental lifecycle may derail potentially promising innovations. It is also necessary to carefully balance benefit and risk. A product with moderate risk potential may be tolerated provided there are significant benefits, and adequate control measures are available. Questions also arise regarding who should carry out and fund health risk assessments for new materials. Manufacturers clearly have responsibilities, but there are also advantages in centrally funded, objective assessment. Particular complications arise when assessing the health risks for nanomaterials in view of their wide variability and the lack of adequate exposure data. There is no requirement to label nano-enabled building materials. This makes it difficult to assess the extent of their usage, and hence also to determine the health risks to those working with them, or exposed to them due to demolition or recycling at the end of the product or building life. Manufacturers, researchers, governments and wider society share responsibility for addressing these challenges. However, there are steps which constructors can take in the interim to minimise the impact on those working with these uncertainties.

Keywords: nanotechnology, nanomaterials, demolition, health risk.

INTRODUCTION

Nanomaterials have one or more dimensions between 1 and 100 nm – for comparison, consider that a typical human hair is around 80,000 nm in diameter. Engineered nanomaterials (ENM) are those which have been intentionally produced, rather than occurring naturally or arising as a by-product (e.g. from volcanos or traffic pollution). They can offer exciting properties, sometimes very different from those of materials in their more usual ‘bulk’ form. For example, gold becomes soluble at the nanoscale and titanium dioxide, traditionally used for its whiteness, can appear transparent. Nanomaterials have been identified by the European Union as a Key Enabling Technology, important for future employment, financial growth and technical innovation. There are prospects of flexible phone screens, more efficient solar panels, and advances in lithium ion battery design. In medicine, there is potential for drugs to

¹ w.jones2@lboro.ac.uk

target tumours directly without damaging surrounding tissues, to fight multiple sclerosis and maybe even to repair damaged spinal cords. In construction, nanomaterials (predominantly silicon dioxide and titanium dioxide) are found in ‘self-cleaning’ windows, often used in conservatory roofs; in self-compacting concrete; and in water resistant coatings (van Broekhuizen and van Broekhuizen 2009). Other applications such as pavements which reduce airborne pollution are also being developed, although not yet in widespread use.

Our ongoing project, sponsored by the UK’s Institution of Occupational Safety and Health (IOSH) is looking at the use of nanomaterials in the construction and demolition sectors. The main purpose of the study is to assess the health risks which may arise when buildings which have been built using ENM-enhanced products are demolished. We are addressing this by:

- Developing a database of construction materials which are, or appear to be, nano-enabled
- Assessing sample products using material characterisation techniques (such as scanning electron microscopy, and energy dispersive X ray spectroscopy) to identify whether they are nano-enabled and describe the nanomaterial used
- Interviewing representatives from the construction and demolition sectors to understand where nano-enabled products might be used and also to identify the processes which will be used to demolish buildings at end of life
- Laboratory replication of common demolition techniques to assess their impact on nano-enabled building products, and to explore the likelihood of nanoparticle release

Our work has highlighted the difficulties of managing the health and safety risks of materials which are at a relatively early stage of development. In this paper we use examples from our research to explore these issues, many of which will arise when managing risks from novel materials and processes more widely. First, we discuss the challenges of assessing the hazard and exposure risk from nanomaterials. We then consider the need to balance benefit and risk. We address practical issues of risk assessment – including the timing of such assessment, and whose responsibility it should be to carry out appropriate hazard evaluation. Finally, we consider the importance of disseminating the right information to the right individuals. In each section, we suggest how these challenges might be addressed, including intervention at government or societal levels. We also consider how constructors can continue to manage their work safely despite the lack of clarity in some areas.

A particular complication with nanotechnology is that there are many different definitions. Some discussions focus only on materials which contain nanoparticles. Alternate definitions encompass materials which have internal dimensions (spaces or pores) at the nanoscale even though they do not contain nanoparticles. Our research for this paper has taken a broad approach, considering any material which has some dimension at the nanoscale or which is described by the manufacturer as using nanotechnology.

ASSESSING THE HAZARD FROM NANOMATERIALS

Hazard relates to potential impact on workers, other people, and the wider environment – for new substances, the question is, ‘how toxic or dangerous is this material to those who may come into contact with it?’ A key concern about the health risk from nanomaterials relates to their relatively high surface area, which increases their reactivity. For example, non-nano titanium dioxide might have a surface area of

around 2m²/g, compared to nano titanium dioxide with a surface area of perhaps 175m²/g depending on the particle size and structure (Xiong *et al.* 2013). Surface area however, is only one part of the equation, as there are substantial differences between materials in their toxicity. In fact, to talk about the health risk of ‘nanomaterials’ is no more meaningful than to refer in generic terms to the health risk of ‘chemicals’ or ‘gases’. Health risk varies with chemical composition, but also differs between materials with the same chemistry. For example, one type of nanomaterial which has caused concern is carbon nanotubes (CNTs), largely because of their fibre like structure and their bio persistence, factors which they share with asbestos. Carbon in the form of carbon black, by comparison, has a very different structure. It has been used in tyres for around 100 years and is considered to be one of the lower risk nanomaterials, carrying toxicity comparable to that of other respirable dusts.

CNTs themselves show wide variation – they may be single walled (a single, rolled sheet of graphene, with a diameter of around 1 nm) or multi walled (multiple tubes inside one another, and a diameter between 2 and 100 nm). They may also be short (<5 µm in length) or long (typically 5-50 µm but potentially much longer); straight or tangled; and may or may not encapsulate additional substances such as heavy metals. All of these characteristics influence toxicity, and there is similar variation for other nanomaterials. For example silica (silicon dioxide) exists in two forms – crystalline, which is found in its non-nano form in cementitious products and is a major cause of ill-health in the construction industry; and amorphous which is a less hazardous material, and is the form more commonly used at nanoscale proportions (for example as ‘silica fume’ used in many high performing mortars and concretes). Other materials such as titanium also exist in multiple forms. The hazardousness of each nanomaterial can therefore be influenced by many characteristics including size, shape, solubility, aggregation state (whether and how the particles clump together), surface charge, and many other factors. This makes it difficult to draw firm conclusions regarding health effects, particularly as many health risk studies do not describe the nanoparticles used to this level of detail. Consequently, many authorities, including the HSE in the UK advocate a precautionary approach – in the absence of evidence that nanomaterials are safe, action should be taken to avoid harm which could plausibly occur.

Applying this approach to construction management is made difficult by uncertainties over which nanomaterials might be used and where. Most products which contain nanomaterials are not required to be labelled as such, and safety data sheets do not typically include this level of detail. Our current study initially identified around 150 products which were believed to contain nanomaterials (based, for example, on the name, properties or description of the product, or on manufacturers’ claims). We have tested 20 of these so far and found that 16 contain either a small or very small number of nanoparticles and the remaining four contain none. A database in the United States (CPWR 2015) has identified around 400 construction products which might be nano-enabled based upon similar criteria, but is unable to identify the nanomaterial supposedly contained in most of these.

This lack of clarity is uncomfortable and it is important that research continues to identify more conclusively the hazardousness of the particular nanomaterials which are most likely to be found in construction products. However, the uncertainty needs to be considered in context. There are significant risks already present in the construction industry, including silica dust, sensitising agents and solvents; whilst the literature so far has failed to show significant evidence of harm for most nanomaterials, with the exception of quantum dots (which are unlikely to be used in

construction) and carbon nanotubes (Krug 2014). Good implementation of standard control measures (such as ventilation and extraction systems, high standards of hygiene and welfare, and provision of suitable protective equipment when necessary) remain the most effective route to protect against the known hazards in the industry as well as new (or unrecognised) hazards, in the absence of evidence to the contrary.

ASSESSING EXPOSURE TO NANOMATERIALS

To understand the risks which might arise from the use of nanotechnology, we need a good understanding not just of how hazardous particular materials are, but also what the potential is for exposure in construction. We need to know the quantities of materials being used and the likelihood of particle release at various stages of a building's life – construction, maintenance and modification, demolition, and recycling. Unfortunately, the evidence regarding potential exposure to nanomaterials is even less substantial and conclusive than that relating to their hazard profile (Savolainen *et al.* 2010).

Assessment of particle release needs to be performed on real construction products, as it is influenced by many factors such as the nature and quality of the materials themselves and the matrix in which the nanomaterials are contained, as well as the methods and tools used. Planning such experiments is made more difficult by the lack of certainty over which products are nano-enabled.

A particular issue in exposure assessment is how to take account of degradation over time. Epoxy resins, often used in paints and coatings for example, can break down under the influence of ultra violet light, potentially leading to embedded particles being more easily released from the matrix that they are secured in. There is evidence that the combination of weathering and machining processes (as might occur from sanding or drilling) can lead to free CNTs being released from composite materials (Hirth *et al.* 2013). This is of particular concern in demolition where materials may have been exposed to the elements for many years, but it is difficult and expensive to replicate these processes accurately in a laboratory environment.

Finally, there are challenges regarding the actual measurement of nanoparticle release, particularly differentiating between released particles and background levels. Broekhuizen (2011) measured particle release from a task involving the drilling of nano-enabled concrete but found that cigarette smoking in the vicinity had a far higher impact on particle counts. Also, nanoparticles may be released from products even though they were not added during manufacture. For example, the demolition of ordinary (non-nano) concrete results in the release of particles of all sizes, including a high proportion of nano sized ones (Kumar and Morawska 2014). Again, this emphasises the importance of those working in construction continuing to implement good practices to protect workers against both the familiar and unknown risks.

It is essential that constructors keep accurate records of the products used in their buildings, for example using the health and safety file required under the UK's Construction (Design and Management) Regulations (2015). This will make risk assessment easier for those who modify or demolish the buildings in future years, once more detailed guidance is available. However, for such guidance to be produced in due course, action at a national and international level will be important. Firstly, improved labelling of products would make it easier to identify candidate materials for exposure testing, and also to understand the potential for exposure more widely. The EU is currently consulting on possible changes to REACH legislation (Registration,

Evaluation, Authorisation and Restriction of Chemicals, 2007) to improve the availability of information to those who use nano-enabled products. There is reluctance within the EU to introduce legislation specific to nano-labelling and registration, although France, Belgium and Denmark have all introduced their own (widely varying) regulations to this effect (Bochon 2015), all of which may contribute to increased availability of information about the extent of usage. In addition, it is important that ongoing and future research considers exposure potential and particle release from real construction products during standard building processes. For those working in demolition, the results of testing which includes weathering and life cycle approaches are particularly important.

BALANCING RISK AND BENEFIT

As a society we are familiar with the concept of balancing benefit and risk. Drugs with severe side effects are approved, but only for use in life threatening diseases; the armed forces prepare their recruits for battle situations using rigorous training methods unlikely to be considered acceptable in other sectors. In construction too these judgements are made – paint with a slightly higher level of toxicity might be used if it lasts twice as long as a safer product, and thus will reduce the need for repainting. Decisions are sometimes made in construction which are more questionable, for example working at height without proper fall protection, to enable work to proceed more quickly and cheaply: but at a high risk for those doing the work.

Similar judgements are important with nanomaterials. Nanosilver is a material which has antimicrobial properties and can be used to reduce infection spread in hospitals and care homes. However, it might also have environmental effects as a consequence of its toxicity to microbes, and it may encourage the development of resistant microorganisms. An EU opinion (SCENIHR 2014) notes that there is a gap in our knowledge and observes that some in the peer-reviewed literature recommend usage be limited until this is addressed, particularly in consumer products (such as washing machines, socks and house paints) where the benefits are less tangible.

Construction is often a conservative industry, favouring methods and materials with proven reliability and longevity over new products and processes. Cost is also a key driver and this too has the potential to slow the introduction of new materials regardless of their apparent benefits. However, societal pressures can influence the adoption of new practices. For example in the current work we found a growing use of nano-coatings on windows in response to requirements for greater thermal efficiency of buildings. Other nano-enabled construction products might also contribute to reduced environmental impact such as concretes which use less energy and raw material in production. It is possible therefore, that higher risks from some materials may be tolerated in future if climate change concerns increase and have a greater influence on priorities. It is important that any such decisions are made based on a full understanding of the facts regarding both the benefits and the risks.

Responsibilities for balancing benefit and risk also lie with designers and manufacturers of new nanomaterials: they need to consider this at an early stage, and throughout the development process. An EU-funded project (LICARA, Som *et al.* 2014) recommends that where benefits outweigh risks, development can proceed; where benefits and risks are balanced, steps need to be taken to improve the benefits or to control the risks; and where risks are high, development should not generally proceed, however great the benefits.

TEMPERING INNOVATION WITH CAUTION - ISSUES OF TIMING

Health and safety risk from new materials and processes should be addressed early to ensure that any risks are properly understood before they are introduced on a widespread basis. History contains numerous examples of hazardous materials being identified only in retrospect, when those working with certain substances developed particular diseases. Examples in construction include Chromium VI, lead paints and of course asbestos; examples in wider society include tobacco, 'trans fats' in foods, and environmental pollutants such as chlorofluorocarbons (CFCs).

There is little doubt that nanomaterials are being used in the construction industry and that this is likely to increase - it has been suggested that 50% of building products are likely to be nano-enabled by the year 2025 (AECOM 2014). It is arguable whether this expansion is advisable, given the lack of clarity over the materials in use and the difficulties in predicting the potentials for exposure. The issue of timing is well illustrated by the addition of CNTs to concrete - in the early stages of our study it appeared from the academic literature that this was potentially quite widespread, taking advantage of the strengthening and electrically conductive characteristics of the nanomaterial. This was concerning given the evidence that some forms of CNT are particularly hazardous, and the lack of information regarding exposure potential during the various stages of demolition. It appeared that the technology had progressed without adequate assessment of the risks, and without consideration of the control measures which might be appropriate. However, it became apparent subsequently that the high cost and practical challenges associated with CNTs had delayed their transition from laboratory to industry. Only in recent months have there been reports that field testing of CNT-enhanced concrete is taking place with a view to commercialisation in 2016 (Eden Energy 2014); therefore testing is required now to improve understanding of their risk profile throughout the life cycle of the product and to provide proper guidance to those who might work with them.

It is perhaps inevitable that the use of nanotechnology will continue to develop ahead of detailed information on the hazards of specific materials. As discussed above, the best solution for those working in construction is to adopt a precautionary approach, typically involving the control methods already used to manage known hazards in the industry. More sophisticated risk assessment will become possible as the data become clearer, enabling better distinction between those materials which might or might not give real cause for concern. For example, some characteristics of nanomaterials such as being fibre shaped make them more hazardous, and others such as being soluble make them less so. Work is ongoing to refine such methods for use in nanotechnology (Bergamaschi *et al.* 2015). Guidance specific to the use of nanomaterials in the construction industry is also expected to be published shortly by SCAFFOLD. This is a large European project which has assessed the risks of nanomaterials and the potential of exposure during construction and maintenance tasks.

RESPONSIBILITIES FOR RISK ASSESSMENT OF NEW MATERIALS

There are legal requirements for manufacturers to gather information on the health and safety risks of their products. Under REACH in Europe, for example, manufacturers are required to assess and manage the risk from the materials that they sell and to

provide appropriate information for their users through safety data sheets. Similar provisions apply in other countries such as the United States.

It could also be argued that manufacturers have a moral duty to ensure the safety of the products that they market, and to share the relevant data with their customers. For example, Responsible Research and Innovation is an EU approach which expects business to work with researchers and the public to ensure that the needs of all parties are aligned (Sutcliffe 2011). There is evidence that some companies recognise this responsibility. For example Bayer (who developed 'Baytubes', one of the early CNT products) states on its website, 'we assess the possible health and environmental risks of a product along the entire value chain. This starts with research and development and continues through production, marketing and use by the customer through to disposal' (Bayer 2015).

In reality it is difficult to evaluate how companies make such judgements, and how they balance these legal and social responsibilities with accountability to their shareholders. For example, the Australian/American company which has started trialling CNT-enhanced concrete reports that it has 'resolved' health and safety concerns through the inclusion of the CNT in a 'liquid admixture' and by using only a low percentage in its product (Eden Energy 2014). This in itself is not evidence that the material will be safe at various stages of use, although further information may become available before the product reaches commercialisation.

Independent testing of materials ensures a degree of neutrality and provides confidence and reassurance. It is also able to address broader issues rather than being limited to individual products; and findings can be made publically available, without the confidentiality concerns which may inevitably arise at a company level. Thus the EU has spent around €5bn on nano-technology research for the period 2002-2013, including a range of studies specifically addressing health and safety concerns (e.g. Scaffold, NanoMicex, Sanowork, Marina and NanoReg); and the United States committed €15bn over a similar period. However, it can be challenging to undertake testing on targeted products. During our research it has proved difficult to obtain samples of many nano-enabled construction products, particularly those which are sold only to professional users. Some companies have requested non-disclosure agreements; others have simply ignored requests to participate in the research.

There is little that construction managers can do to directly influence the research agenda at this stage. It is to be hoped that assessment of nano-safety risk will continue at all levels including life cycle studies to take account of the long term risk, the impact of weathering etc. At the same time, improved transparency by producers of new materials will make it easier to interpret and act on research which has been published. For example, data which show the risk profile for silicon dioxide or titanium dioxide are of limited value if poor labelling makes it difficult to identify products which might contain them.

FUNDING OF RESEARCH AND DEVELOPMENT

This question is linked to the previous one: there are potentially high costs associated with evaluating health risks from new products. This may be problematic where small companies are involved in developing a material or product, and may be reluctant (or unable) to commit the necessary resource until they are confident that a product is commercially viable. There is some evidence from France, where all nanomaterials are required to be registered centrally, that this could adversely affect the innovation

and development of nanomaterials. The reported costs of registration (including characterisation of nanomaterials in terms of size, shape etc) are around €15 000 per company and some French companies report being asked by partners specifically to provide 'non-nano' products in order to avoid these costs (RPA *et al* 2014).

Where costs are incurred by organisations, they will inevitably be passed on to customers. This has particular implications for the adoption of nanomaterials in construction given the high volumes of materials used and the strong focus in the industry on price and value.

MAKING INFORMATION AVAILABLE

The importance of engaging the public in research outcomes and innovation is a strong theme in Europe, seen for example in funding calls from the EU and other research bodies such as the ESPRC. There is a benefit in sharing research in this way; in the absence of good information, those with concerns may draw their own, potentially erroneous, conclusions. Such misinformation has been suggested for example, as one possible reason for the failure of Europe to accept genetically modified (GM) products (Sutcliffe 2011).

Our interviews revealed very limited awareness of nanomaterials amongst those either working in construction and demolition or those selling building products. A similar situation has been reported in Europe and the United States, with less than half of those potentially working with nanomaterials in construction being aware of this (van Broekhuizen and van Broekhuizen 2009; Lippy 2015). In practice, there is limited benefit in managers and workers in construction knowing simply whether or not particular products are nano-enabled, given the lack of clarity over what this really means in health terms. More important is that those who carry out risk assessment in construction are able to rely on the data provided, for example in safety data sheets. A priority, therefore, should be for material producers and sellers to know that their products are nano-enabled, and to ensure that data sheets are comprehensive, accurate, and based on the most current findings regarding nanomaterial hazard. ISO guidance is available to support them in this (ISO 2012).

Centralised data collection is also a good way forward, assessing risk at an industry level, and then converting it into user-friendly tools for employers and workers. This is the approach of the current research, and also that taken by the SCAFFOLD project mentioned earlier, which will shortly publish an on-line risk assessment tool for those working in construction.

CONCLUSIONS

Nanotechnology is offering exciting opportunities and providing industry with new materials and better performance from existing materials. Construction is one of many areas where there could be great benefit. However, there are concerns regarding potential health risk, and although the knowledge base is developing steadily it is not yet complete. Therefore it is still necessary to adopt a precautionary approach. Health risk for construction workers is particularly difficult to assess, as products are rarely labelled and minimal (or no) information on material composition is provided in many cases. There is even less evidence regarding the potential for exposure, particularly in demolition where it is important to consider the impact of long-term degradation as well as the effects of aggressive demolition techniques.

Those managing construction and demolition should adopt best practice in health and safety to protect workers against existing hazards such as silica dust and a variety of irritants and allergens. These remain important hazards regardless of the introduction of new materials, and similar protective methods are likely to be effective in both cases. However, there is also scope for constructors to ask challenging questions of their suppliers, to encourage them to understand better the products that they supply and to ensure that safety data sheets for nanomaterials are comprehensive, accurate and appropriate.

As nanotechnology has advanced over the last 15-20 years and change continues to accelerate, the information we need to adequately assess and manage risk has failed to develop at the same rate. The same challenges are likely to apply to other processes and materials outside nanotechnology, as developers seek new ways to innovate and differentiate themselves from their competitors. It is unlikely that legislation will be able to keep up with these changes, so designers and developers of new materials must take responsibility for ensuring that the potential risks of these products are properly evaluated and kept under review as new data emerge.

Centrally funded investigation will continue to be important to ensure that such work is comprehensive; and to hold industry to account and ensure that commercial interests are not allowed to take precedence over health and/or safety. There is also an important role for governments and industry bodies to draw together findings from various sources, identify common themes, and translate technical data into user-friendly guidance. This combination of approaches provides the best chance that we can adopt nanomaterials and other new technologies in a safe and successful manner whilst ensuring that disproportionate anxiety and lack of understanding do not detract from the process and reduce innovation.

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EXPLORING THE POTENTIAL FOR USING VIDEO TO COMMUNICATE SAFETY INFORMATION TO CONSTRUCTION WORKERS: CASE STUDIES OF ORGANISATIONAL USE

Ruwini Edirisinghe¹, Helen Lingard and David Broadhurst

RMIT University, Melbourne, Australia

Legislation mandates that employers provide sufficient health and safety training and communicate relevant health and safety information to workers. However, the literature suggests that, globally, health and safety management in construction has to deal with a workforce with growing language and literacy barriers. Hence, conventional written and verbal safety communication approaches are of limited effectiveness. Research suggests that traditional safety training methods and the use of overly complicated, lengthy written statements about how work should be conducted are not very effective. A Melbourne-based firm (CodeSafe Solutions) has developed an innovative process for capturing and communicating health and safety training and safe operating procedures to field based workers using digital media (films) that can be accessed using Quick Response (QR) code technology. Two case study organisations in the water resources and home insulation sectors of the Australian construction industry are used to explore the potential of the CodeSafe system in communicating health and safety and technical information to workers. Data collected from the interviews and an examination of incident reports and video usage data were analysed in this study. Managers perceived the CodeSafe system to be beneficial and well received by workers. In one case study organisation, the introduction of the CodeSafe system coincided with a reduction in injury rates. However, without using a robust experimental design, causal inferences about the impact of the system cannot be made. Worker who were involved in making the films believed films would be an effective communication tool. However, the barriers to use the digital/mobile technology revealed from the interviews include limitations to use smart phones to access the material and limitations of internet connectivity to access the material. In addition, organisational and national level regulations related to mobile phone use on site significantly influence the technology adoption.]

Keywords: health and safety, visual communication, visual learning, QR code, safety training, safe work procedures.

INTRODUCTION

Globally, the construction industry records high fatal and non-fatal accident rates compared to other industries. According to the European Commission, the construction sector in Europe recorded more than one in four (26.1 %) fatal accidents at work in 2009. In 2012, the USA construction industry reported about one fifth (19.6%) of worker fatalities (OSHA 2013). Given the industry's poor record, the Australian Work Health and Safety Strategy 2012-2022 has identified the construction

¹ ruwini.edirisinghe@rmit.edu.au

industry as one of the priority industries for safety improvement (Safe Work Australia 2012).

Communicating health and safety in construction industry

Employers' responsibilities for health and safety (H&S) are mandated by law and include providing information to workers concerning H&S at the workplace. Responsibilities include providing adequate H&S training and communicating safety rules, policies, and procedures in a manner that can be understood by the workers. However, challenges exist in communicating H&S in the construction industry due to literacy barriers (Loosemore and Andonakis, 2007) and ethnic diversity (Brunette, 2005). Literacy barriers arise because construction workers have relatively low levels of educational attainment compared to workers in other industrial sectors (Loosemore and Andonakis, 2007). Communicating H&S is also believed to be difficult due to language and cultural differences within groups of migrant workers, so called hard-to-reach workers (Brunette, 2005). Globally, growing barriers to communication arise due to the increased involvement of migrant workers in construction projects. These challenges have been observed in the UK (Bust *et al.*, 2008), the USA (Brunette, 2005), Australia and Singapore (Loosemore and Lee, 2002).

Are traditional H&S training methods appropriate for construction industry?

Research demonstrates that traditional H&S training methods are not particularly effective in the construction industry partly due to literacy and language barriers of learners, but also due to the educational approach underpinning this training (Wilkins, 2011). Pedagogical approach involved an “*expert*” instructor transmitting knowledge to recipients is arguably inappropriate and ineffective when applied to adult learning (Vella, 2002). We also acknowledge that communication is a complex problem in construction industry where the social factors such as workers' motivation, willingness and interest to take in information and cultural values (Hartmann 2006) also contribute to the communication problem in addition to the technological factors. Despite, as a technological solution, it is important that alternative and appropriate H&S training methods are developed and implemented in the construction industry. More specifically, Loosemore and Andonakis (2007) recommend conducting H&S training using multimedia and multi-languages.

An example of using technology to provide interactive and engaging H&S training is gaming. A gaming-based virtual construction site has been proposed as an effective method to achieve learning outcomes in construction H&S (Liaw *et al.*, 2012). Gaming-based H&S induction training for construction workers was also proposed by Greuter *et al.* (2012). This game-based training covered hazard identification and hazard management/control and also linked productivity with H&S.

Are written H&S rules, policies, and procedures effective in communicating H&S in construction industry?

Traditional methods of communicating H&S rules, policies and procedures in construction utilise the written form. For example, Safe Work Method Statements (SWMSs) are mandated for high-risk construction work in Australia. While these documents are criticised for being overly long and complicated, Besnard and Greathead (2003) recommend that rules and procedures should not aim at being exhaustive but rather workable.

The combination of relatively low levels of literacy with possible language barriers and lengthy written statements about how work should be conducted create problems for comprehension. Hence, long written documents are arguably an ineffective means

to communicate H&S rules, policies and work procedures to construction workers. Bust *et al.* (2008) advocate that it is crucial to identify audio-visual methods that can effectively communicate construction H&S to workers employed in multicultural context to overcome these barriers.

Use of digital and mobile technology for communicating H&S

The provision of critical H&S information in visual form is an effective way to ensure that important information is communicated to workers whose levels of language and literacy may be low. One of the challenges in using alternative audio visual forms for communicating H&S to field based construction workers is how to disseminate learning resources and H&S procedures at the workplace so that workers can choose when they want to access them. Quick Response (QR) codes have been recently incorporated in accessing learning resources successfully (Bonifacio *et al.* 2012; Chaisatien and Akahori, 2007).

QR code technology for accessing learning resources

A QR code is a two-dimensional bar code. The use of QR codes has been popular as they became license free and with the increasing use of smart phones. Some examples of the use of QR codes to support learning and teaching are provided below.

Liu *et al.* (2010) developed a novel QR code and handheld augmented reality (AR) supported mobile learning (m-learning) system called Handheld English Language Learning Organization (HELLO). The HELLO system provides learning resources and functions to facilitate English learning for undergraduate students. Bonifacio *et al.* (2012) created a system to use QR Codes to access the elements of the periodic table. The periodic table with the audio description of elements is proposed as a learning resource for high school students and first year undergraduate students. QR codes have also been used to provide a lecturer support system (Chaisatien and Akahori, 2007). QR codes were attached to the posters displayed in the classroom to aid student learning. Other activities of this lecturer support system that used QR codes include student registration and theme registration. In the UK, the University of Bath encourages to use QR codes in education where a getting started guide for academics was developed (Ramsden, 2008).

Successful use of QR Code to access learning resources in number of disciplines indicates its potential to be a promising technology to access H&S information recorded in audio visual form. Adopting QR code technology as a critical information dissemination mechanism needs to carry a level of due diligence around choosing the right, secure and robust QR code generator platform, to ensure data transfer is reliable (not corrupted) and access is instantaneous.

RESEARCH METHODS

The CodeSafe system

The CodeSafe system has the potential to address some of the above challenges in communicating H&S and technical information to field based workers in construction industry. The CodeSafe system is a systematic method for capturing, representing and disseminating construction workers' tacit H&S knowledge in visual (film) format. The CodeSafe method addresses the need to change both organisational H&S delivery practices and workers' behaviour through the key elements given below.

22. Development of healthy and safe work tasks using workers' own tacit knowledge: The involvement of workers in writing, acting and producing films

reflects an engagement, rather than an enforcement orientation to H&S. The discussion on this element is out of focus of this paper. However, the details are available in Lingard *et al.* (2015).

23. Representation of H&S procedures and learning materials in video format: Films featuring colleagues showing the safe way to perform a task in the field may support the transfer of knowledge more effectively than traditional modes of training delivery. Filming workers undertaking tasks safely can be a more effective way of communicating H&S information (policies, rules and procedures) to construction workers than traditional written documents and manuals.
24. Use of QR code technology to improve the dissemination of critical H&S knowledge throughout the industry: The use QR code technology to disseminate video enables workers to access H&S information quickly and easily when they need to use it – particularly when they are at the work-site, at the point of task.

Research Question

The research sought to explore the effectiveness of the CodeSafe system in communicating H&S knowledge in construction industry. Particularly this paper focuses on the case study organisations that used the CodeSafe system to investigate the potential of the CodeSafe system in improving H&S.

The research initially conducted in-depth interviews with the managers of the organisations who directly involved in the CodeSafe's video-based intervention. Five managers were interviewed from four organisations. During the interviews, CodeSafe system's potential to impact on H&S performance of the organisation was questioned. Any available quantitative data and statistics were also collected subsequently.

In one case study organisation, field-based observation of workers engaged in video development was conducted together with the interviews of the workers. Five workers were interviewed who participated in the video development. It is acknowledged that this sample might be skewed because the workers involved in making the videos could be biased to have a positive perception. Workers' willingness to use the digital mobile technology and the CodeSafe system were also questioned. All the interviews were audio-recorded and transcribed before being subjected to content analysis.

This paper reports use of the CodeSafe system in the two CSOs. Where possible, quantitative data indicating the use and H&S statistics is also provided.

CASE STUDIES OF ORGANISATIONAL USE OF THE CODESAFE SYSTEM

Case Study Organisation 1 (CSO 1)

H&S challenge

CSO 1 was an alliance between a major construction company, engineering design firm and a government-owned statutory water authority. CSO 1 was responsible for improving, maintaining and expanding water storage systems and the distribution network for reliable and high-quality water.

CSO 1 developed a cultural change program to encourage workers at all levels within the organisation to act as drivers for improved H&S. A survey undertaken in the organisation at the same time that the CodeSafe system was developed, revealed that the workers preferred H&S requirements and procedures to be communicated as

demonstrations rather than as written procedure documents or SWMSs. The CSO 1 adopted CodeSafe system's engagement to develop mobile visual H&S procedures as a means to communicate H&S information more effectively.

Introduction of the CodeSafe system

CodeSafe initially developed two mobile visual procedures as a pilot, one for the use of a demolition saw and the second showing how to fit a rubber ring in a large diameter water pipe. CSO 1's H&S incident data was carefully examined to identify other areas in which visual procedures could be implemented to reduce the risk of accidental injury. CSO 1 developed a series of procedure-specific short videos which were made available to the workforce at point of task via QR code technology. These procedures included asbestos removal, dealing with chemical spills, working in a confined space, building a mobile scaffold tower, H&S aspects of electrical installations in construction, and the provision of site emergency information. All digitised visual procedures were distributed to workers using QR codes placed on relevant equipment and in the site sheds so that workers can access them using the smart devices such as phones and tablets. Social media, the organisation's intranet and USB sticks were also used to disseminate the visual procedures within CSO 1.

As a result of the CodeSafe's collaborative approach which engages H&S with technology, CSO 1 was awarded the Australian Water Association Water Industry Safety Excellence Award in 2012.

Impact Statistics: Video Usage Data Analysis

Figure 1 shows the video usage data of each visual procedure during the period of the CodeSafe system implementation in CSO 1. "Number of hits" represents the number of times each video was viewed to completion using a mobile device via scanned QR codes.

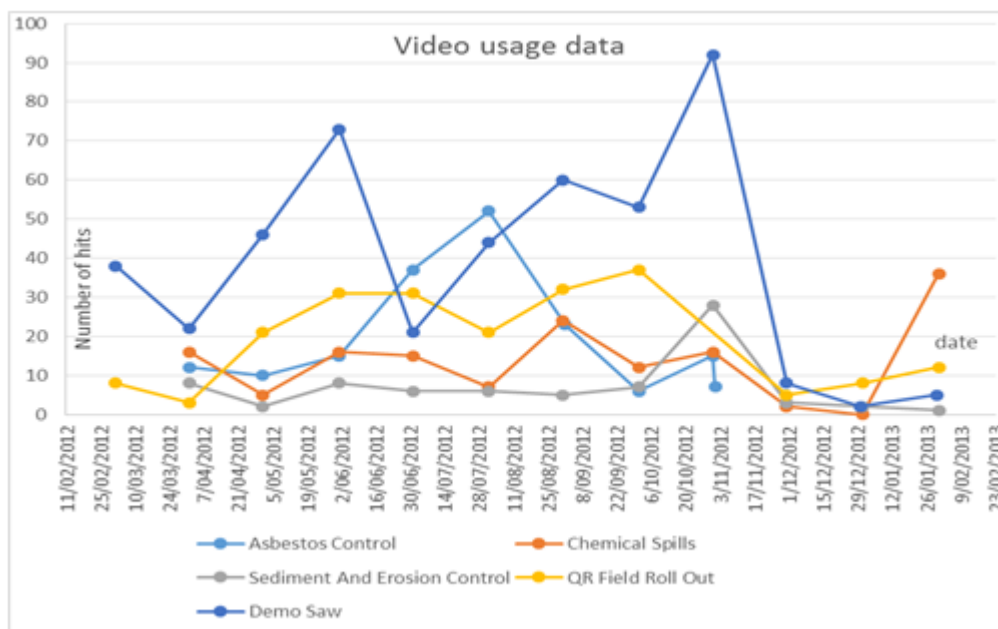


Figure 1: Video usage data in CSO 1

It is noteworthy that video usage fluctuated over time and some videos were viewed more frequently than others (e.g. demolition saw video). This may be due to certain activities ramping up and dropping off at different stages of the projects delivered across CSO 1. For example, the peak usage of the demolition saw video in November

2012 coincides with the receipt of the Australian Water Association Water Industry Safety Excellence Award, which may have prompted renewed interest in the video.

Perceived impact: Interview data

One manager of CSO 1 talked about the positive impact of the CodeSafe system in communicating H&S as, “...*the industry we have to become more visual in that communication so CodeSafe was a great emerging technology to deliver that instantaneously and I think discretely...*”

Another manager in CSO 1 who was involved in work procedure development also mentioned the ability to use CodeSafe's safe procedure related videos as a refresher training: “... *the benefit of, it's just refreshing people's memories on what the required procedure was.*”

Case Study Organisation 2 (CSO 2)

H&S challenge

CSO 2 is an Australian company, which provides insulation and energy efficiency products for the residential and commercial building sectors. The vision for the business is to “*Safely Deliver Extraordinary Value to Our Customers*”. After reviewing organisational and industry incident data, CSO 2 identified the top risk areas (industry wide) that had the potential to cause a workplace fatality. These areas were electrical safety, working at heights, traffic management, mobile plant operation, and working in hot conditions.

Introduction of the CodeSafe system

CSO 2 initially used CodeSafe's consultative and collaborative approach in the development of visual procedures for electrical isolation and load restraint, trailer hitching and working in hot conditions with the residential installers. CSO 2 then engaged with commercial installers and construction supervisors on commercial sites to develop the visual procedures in the commercial sector. Qualitative analysis of the manager and workers' interview data evidence that the system has been very well received by workers.

Injury Rate Data

CSO 2's Total Recordable Injury Frequency Rate (TRIFR) data was analysed. Figure 2 shows the TRIFR data over a 12 months period. The figure shows a steady reduction in TRIFR that coincided with the implementation of the CodeSafe system at CSO 2 (indicated by the vertical line).² While it is not possible to draw any conclusions about causation, CSO 2 has reported an improved H&S performance since implementation of the CodeSafe system.

Impact Statistics: Video Usage Data Analysis

CSO 2's video usage data is shown in Figure 3. It is noteworthy that the video usage fluctuated over time and some videos were viewed more frequently than others were.

Activities of CSO 2 during the period of video usage data were investigated in order to understand the peak usage of video data. CSO 2 was invited to speak at an industry alliance forum in February 2014. The electrical isolation video was demonstrated there. In July 2014, the electrical isolation video was hosted in a state WorkCover authority website. In addition, the videos were used within CSO 2 to raise safety

² Without using a robust experimental design, it is not possible to establish a causal relationship between this injury rate reduction and the implementation of the CodeSafe system.

awareness of sub-contractor groups during the period of June 2014 to October 2014. The video usage might be affected by these organisational activities.

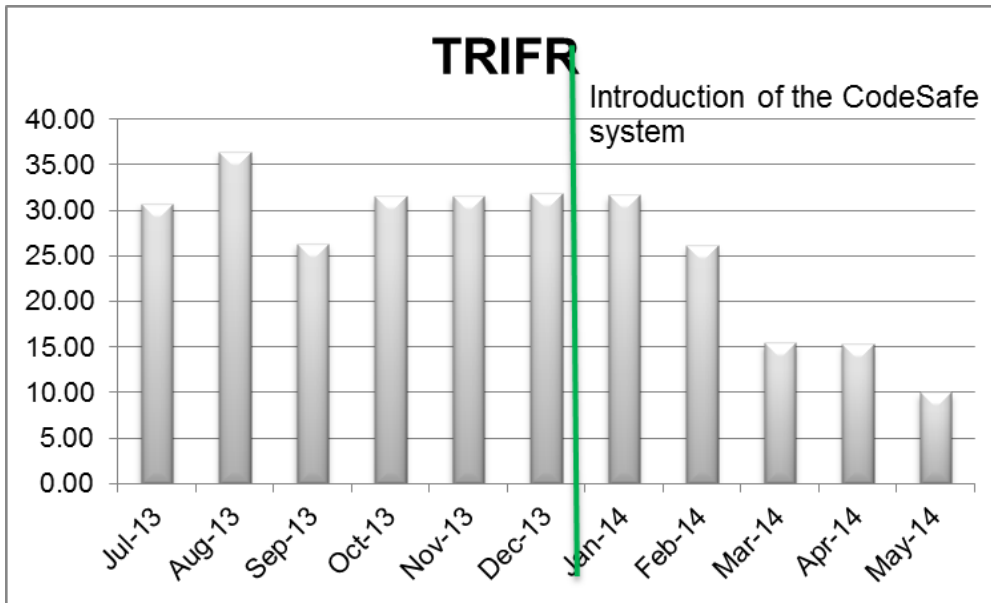


Figure 2: Total Recordable Incident Frequency Rate (TRIFR) for CSO 2 per million hours worked from July 2013 to May 2014

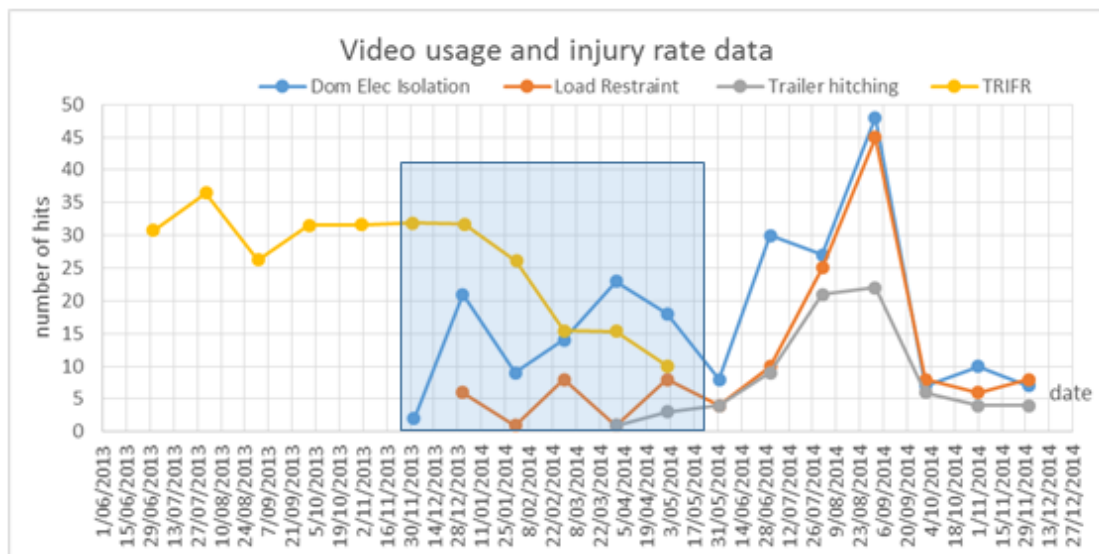


Figure 3: Video usage data and injury rate of CSO 2

Due to the limited overlap of the two datasets of injury rate reduction (TRIFR) data and video usage data (shown in blue colour window in Figure 3) the substantial decrease in injury rate is not possible to correlate with the video usage. Despite, it can be noted that workers' positive response to the CodeSafe system appears to continue.

Perceived Impact: Interview data

The manager of CSO 2 talked about the positive impact of the CodeSafe system in communicating training material: "...empowering the guys to understand the risks and to be able to communicate them ... So the training is simple, the video itself is training support, and you follow the video..."

All workers in CSO 2 who involved in CodeSafe's digital intervention commented that presenting H&S information visually is more effective than using written

procedures. Participants commented that workers would be more likely to look at and understand videos than written H&S procedures.

Limitations of the CodeSafe System

Two limitations of the CodeSafe system in terms of accessing the H&S videos appeared through the interviews and are discussed below

Limitations to use smart phones to access the material.

The use of technology through the smart phones and willingness to access the H&S videos using workers' smart phone was investigated. The mixed responses received include a reluctance to use the personal mobile phone to access the material. The workers also proposed that the organisation provides a smart device (possibly with a larger screen than a phone) for each work group as a solution.

Positive response to use of smart phone as described by one worker is: “... *I don't think I know anyone that doesn't have a smart phone these days. ...*”.

The other responses include willingness to use smart phone depends on the age, and the work environment (industry): “... *It's something that's fairly new, you know. People have old habits and it's like trying to teach an old dog new tricks...for older people I don't think, especially on a construction site, they're not going to get their smart phones out and, look at this industry, a lot of older people don't tend to have smart phones as well. But for the newer generation coming into the business I think it's a perfect way...*” However, the same worker thinks that the use of smart phone technology to provide H&S information would be effective for younger workers: “*But for the newer generation coming into the business I think it's a perfect way. I think it's a good move forward to having safety in the comfort of your pocket pretty much to access*”, The same worker suggests that organisation provides common devices with a larger screen to access information: “... *organisations could actually have like tablets, iPad's. We did a presentation today where we went out to a site and we just looked up on the iPad. So the screens a bit bigger and it means that guys can huddle around you as well, you're not sort of huddled in front of the phone.*”

Another worker expressed the concern that many people do not use smart phones at construction sites. He described how he “*had a smart phone and it got broken on a building site and they're very expensive.*” He now uses a basic mobile phone and continued: “*so my only concern would be – and I know a lot of people who are the same – they don't use smart phones on construction sites because they are delicate things.*” However, the same worker described how this problem could be overcome because the supervisors usually have smart phones and/or tablets that could be provided for each workgroup to enable them to view H&S video content at toolbox sessions and as required.

Limitations of internet connectivity to access the material.

Even though the convenience of the CodeSafe system of being able to view the content in the field was noted some concerns were also raised around limited network coverage to access the material. Issues related to inadequate network coverage in remote sites and signal reception problems in a basement are among them.

For example, one worker commented that although he had never considered accessing information in the field using his smart phone before: “*But it is a good way of – rather than trying to call up the office [for information] you've got it there in your pocket pretty much.*” However, another worker commented on connectivity problems experienced on site as a possible limiting factor to workers being able to access

CodeSafe system's content: “It’s a bit difficult sometimes being in this basement so you don’t get any reception.”

In addition to the barriers revealed through interviews, wider adoption of the technology could be significantly influenced by the organisation and/ or national regulations and policies relevant to mobile phone use on sites. For example, in the UK use of mobile phones is becoming restricted which may hinder the adoption of CodeSafe system.

DISCUSSION AND CONCLUSIONS

To overcome the challenges around limited internet connectivity to access the material, CodeSafe supplied the visual procedures to workers on a Universal Serial Bus (USB) in some organisations. The aim of this was to enable viewing of the videos on demand on a laptop carried by the organisations' managers/supervisors.

We recommend that using information on a USB device, constraints the innovation of the CodeSafe system of accessing learning material using QR codes. In addition, it restricts the availability of information and potential to access knowledge freely. For example, experienced workers might not be comfortable going to a common laptop to access knowledge (feeling embarrassed that they did not possess know-how knowledge) as they would be accessing it on their personal phone privately.

Despite the above limitations, the comments made by the workers and managers who directly involved in making the videos indicated that the CodeSafe system's use of digital video and mobile technology was a convenient and efficient method to communicate H&S to workers. In addition, the video usage data evidence that the workers are watching the video content. The technology could be more effectively implemented in future by considering workers' age, phone use habits, provision for training and provision for devices.

However, due to the methodological limitations of the skewed and small sample, it is not possible to generalise whether the method is effective. There is a need to do further research with a larger sample that includes workers who were not directly involved in making the films to investigate the usefulness and effectiveness of the system.

The quantitative performance data available in the case study organisations were limited. It is therefore not possible to ascertain whether the use of the CodeSafe system produced an improvement in H&S performance in the organisations involved in this research. Hence, even though a continuing usage of video was observed, without using a robust experimental design, causal inferences cannot be made based on the limited quantitative data available.

Future research could also adopt a rigorous experimental approach to analyse the effectiveness and impact of the CodeSafe system to examine the cost-benefit analysis of using this type of digital and mobile technology together with social factors that affect the communication problem such as the workers' motivation, willingness and interest to take in information and the cultural values.

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‘YOU COULDN’T FINISH THE JOB WITHOUT BREAKING THE RULES’: COMMON SENSE SAFETY ON A LARGE CONSTRUCTION PROJECT

David Oswald¹, Emmanuel Aboagye-Nimo², Simon Smith³, Ani Raidén⁴ and Fred Sherratt⁵

^{1 and 3}*University of Edinburgh, King’s Buildings, West Mains Road, Edinburgh, EH9 3JN, UK*

²*School of Environment and Technology, University of Brighton, Brighton, Lewes Road, BN2 4GJ, UK*

⁴*Nottingham Business School, Nottingham Trent University, Burton Road, Nottingham, NG1 4BU, UK*

⁵*Anglia Ruskin University, Bishop Hall Lane, Chelmsford, CMI 1SQ, UK*

Common sense safety refers to the practical knowledge and judgement developed by workers after on-site experience and has been employed by workers of small and micro construction firms for quite some time. This study, which is part of a wider PhD project, aims to explore whether the common sense safety phenomenon is present on a large infrastructure project (+£500m) in the UK. A mixed method approach was implemented through conversations with workers and analysis of qualitative and quantitative safety climate survey data. Considering that the majority of construction workers were employed from smaller subcontractors, it was found that several brought this ‘common sense’ attitude. This caused frictions against the stricter and formalised rules and regulations enforced at a larger organisation. Workers believed that they ‘couldn’t finish the job without breaking the rules’ and only wanted to use specific PPE for the tasks that required them. There was particular resistance with safety glasses, who some believed caused ‘more accidents’ than prevented. In a safety climate survey, 62% of employees agreed they ‘sometimes use their own judgement about following procedures’; and 78% strongly agreed or agreed that ‘using common sense will keep me safe at work’. The supervisors had concerns about a ‘common sense’ approach and middle-management acknowledged that it ‘wouldn’t represent a defence in court’. However, they did not always challenge the workers for not adhering to PPE requirements. For many workers the bureaucracy courtesy of rules and regulations was a big change and one that was unpopular. This can cause frictions in terms of working relationships and meant that greater safety efforts focused on compliance rather than the ‘real’ safety issues.

Keywords: common sense, PPE, safety, trust.

INTRODUCTION

In a report to the prime minister, Lord Young of Graffham (2010) highlighted that a growing compensation culture in the UK construction industry has had adverse effects on health and safety performance. This ‘compensation culture’ has created an environment where organisations attempt to eliminate all risks by all means, even though this objective is unattainable (Lord Young of Graffham, 2010; Gyi *et al*, 1999). The compensation culture attributes blame, and rather than accepting that accidents can and do happen, somebody must always be at fault and financial recompense is seen to make good any injury (Lord Young of Graffham 2010). In a

¹ D.Oswald@ed.ac.uk

study by Aboagye-Nimo *et al* (2013), a 'common sense approach' was brought to light, where workers informally and freely assessed situations and subsequently came up with possible solutions on how to avoid or handle potential hazards on site, while abiding by the law. This informal health and safety management technique was found to be an effective and key advantage that small and micro firms had over large firms. The aim of this study was to explore to what extent such a common sense approach existed on a large construction project, where acknowledgement of this 'compensation culture' may have more significant influence in the goals of the safety management systems in place, than on smaller more informal sites.

COMMON SENSE SAFETY IN CONSTRUCTION

Although safety performance in the construction industry continues to improve, recommendations for further interventions are proposed regularly. For example, Choudhury *et al* (2008) recommended that as a best practice approach, construction organisations need to target eight areas: safety policy and standards, safety organization, safety training, inspecting hazardous conditions, personal protective program, plant and equipment, safety promotion, and management behaviour. Such excessive 'safety bureaucracy' can prove problematic, indeed, Cheng *et al* (2012) found that several safety management practices are perceived as complicated and adversely affect the project performance in the construction industry. However, avoidance of workers' compensation costs have led to firms implementing excessive safety measures (Manu *et al*, 2013). In response to such concerns about excessive bureaucracy in safety, Lord Young of Graffham (2010) produced a report entitled 'Common Sense Common Safety', hoping to challenge this notion of safety red tape which reduces workplace production. The aim of the report was given as follows: *"to free businesses from unnecessary bureaucratic burdens and the fear of having to pay out unjustified damages claims and legal fees. Above all it means applying common sense not just to compensation but to everyday decisions once again"* (Lord Young of Graffham, 2010: 9). The report highlighted that the existing 'compensation culture' in workplaces must be eradicated in order for common sense to prevail. In agreement with Lord Young, Löfstedt, (2011) added that matters concerning 'health and safety' have become increasingly ridiculed and therefore gradually losing its importance in society. In the report, it was indicated that excessive bureaucracy and red tape requirements have been blamed for preventing individuals from engaging in socially beneficial activities, overriding common sense and eroding personal responsibility. The HSE also states that is imperative that workers and working groups disassociate 'safety' from 'bureaucracy' (HSE, 2003: 73). Thus more emphasis needs to be placed on genuine safety and concern for workers' wellbeing if fear of the compensation culture is eliminated (Löfstedt, 2011). Managers of construction firms (especially large ones) have been found to be affected by the fear of the compensation culture the most as they have a larger workforce to cater for and as such, end up creating further strict rules and regulations to prevent such claims from occurring (Wamuziri, 2013).

Common sense is defined as the ability to behave in a sensible way and make practical decisions (Ludhra, 2015). Aboagye-Nimo *et al.* (2013) explain that common sense in the case of construction site safety refers to more than basic level of practical knowledge but requires experience and long term knowledge gained through training, experience, experiential learning in new situations. They found a common sense safety culture to be prevalent among workers of small and micro firms. However, many construction sites and projects are known to be dynamic and involve large, small and micro firms at different stages of the project (Izam Ibrahim *et al.*, 2013).

Due to the fluidity of the activities on construction site, an overlap of cultures between strict and standardised safety measures and common sense safety may exist on large projects. This creates an opportunity for research of common sense safety operating alongside strict safety procedures within large project environments.

RESEARCH METHODS

The lead researcher employed ethnographic methods on a large construction project (+£500m). From October 2012, for a two and a half year period, an overt and 'moderate' participant observer approach was adopted, which can provide a good balance on insider and outsider roles (DeWalt and DeWalt, 1998). In this case the moderate participant observer approach involved being within the research setting one to three times a week during the core business hours. The lead researcher was affiliated with the health and safety department, which led to the health and safety advisors being 'gatekeepers' for their different work areas on the project. A gatekeeper can ease the passage of your entry, make the surroundings and contexts more visible and understandable and introduce a range of possible informants (Pole and Morrison, 2003, p. 26). The researcher was often perceived by construction workers as a trainee safety advisor who posed little threat likely to be due to his youthful looks, age, small height and that he was often with safety advisors. As a PhD student still attached to a university, the researcher assumed the role of a novice or an apprentice. Lofland (1971) describes this as being an 'acceptable incompetent' and Murchison (2010, p.42) states that ethnography can be very productive if the researcher assumes the role of an apprentice (Murchison, 2010, p. 42). Following previous research about the 'common sense' phenomenon, the lead researcher explored the data that had been gathered through conversations with construction site operatives and management (supervisors, foreman, works managers and site engineers) and from a safety climate survey that had been conducted on the project. The survey was administered by an external consultant, comprised of 128 questions, took around 15-20 minutes to complete and had 475 respondents. Of the respondents, 92% were male, 55% labour force, 45% supervised others and 38% have less than six months on the project. The surveys had a mixture of 5-point Likert scales (strongly agree, agree, neither, disagree, strongly disagree), unbalanced 4-point scales (always, sometimes, rarely, never), 3-point scales Likert scales (high, medium, low) and forced choice 'yes' or 'no' questions. Such a mixed-method approach is rare in construction safety research (Zou *et al.*, 2014) but it is argued by Abowitz and Toole (2010) that it can lead to improved validity and reliability of research outcomes. For this study, which is part of a wider PhD, a mixture of quantitative and qualitative findings was used for triangulation, one of the three approaches to mixed-method research (Bryman, 2008). This research concentrates on findings relevant to 'common sense safety' rather than 'common sense health and safety'. Hence, safety issues, rather than health issues are discussed.

SAFETY CLIMATE SURVEY FINDINGS

This inductive study, which is part of a wider PhD project, highlights the key findings on a large construction project. The following section below presents and discusses on results of a safety climate survey. The next two sections are in first person and involve ethnographic conversations with workers from two levels (operatives and middle management).

In March 2013, a safety climate survey was conducted by an external consultant. The following survey results strongly suggests the presence of a common sense phenomenon: 75% strongly agreed or agreed that 'my own experience will keep me

safe at work'; the majority of worker's 'sometimes' (62%) 'use their own judgement about following procedures (always, 10%; rarely, 18%; never, 10%); and 78% strongly agreed or agreed that 'using common sense will keep me safe at work'. When asked if workers would challenge a workmate for no gloves, 56% said 'always'; for no eye protection, 62% said 'always'; for use of a mobile phone in an unsafe place, 58% said always. Along with speeding (54% always) and not clearing up (58% always), these five acts, out of a total of 19 acts, were the least likely to be challenged on site. This perhaps suggested these rules were questioned by workers or not perceived as important as others. The final open-ended question in the survey was 'how do you think we could improve the safety on this project?'. The following answers were related to common sense safety:

'Practical common sense Health and Safety goes out the window to protect persons by generating an exhaustive paper trail. Critical factors like competence go out the window and instead irrelevant rules are enforced'

'Not presuming the next one is a hillbilly but prepare the risk assessment with more emphasis on the existence of common sense.'

'Common sense approach required by safety team'

'Encourage Common sense'

'Everybody uses their common sense including safety advisers'

'Give people more common sense.'

'Use common sense and discretion.'

'Common Sense'

'More common sense approach. Client does not necessarily have the experience to determine what safety measures we as experienced contractors should employ.'

'A more proactive approach is required. Make the workers apply common sense and judgement rather than drilling into them that everything is safe as they take their eye off the ball.'

'Common sense of plant and equipment usage. Awareness of safety. '

'Make the workers apply common sense and judgement rather than drilling into them that everything is safe as they take their eye off the ball.'

'Look at the bigger picture. Gloves and glasses are not always the answer. Try looking at weather conditions, management, experience, foreign labour language barriers and most of all, common sense'

The statistical findings suggest that workers believed in a more common sense approach and sometimes use their own judgement when following procedures. The final open-ended question explored how workers believe safety can be improved, and the evidence suggests that there was desire for a more common sense approach. To further explore the rationale behind these suggestions, a fine-grained ethnographic approach using participant observation was undertaken. For ethical reasons, all names within the following ethnographic passages are pseudo-names.

ETHNOGRAPHIC FINDINGS: THE OPERATIVES VIEW

The following findings are from discussions with site operatives on the project. The section bold sub-heading quotations represent the beginning of a new ethnographic vignette.

'You could not finish the job without breaking the rules'

One afternoon on site, I noticed there was a discussion taking place between one of the construction workers, Paul and a safety advisor. Being curious, I approached to realise that the safety advisor was asking Paul to fasten the crotch-strap for his lifejacket. Paul proceeded to do it but wasn't too happy about doing so, suggesting that the safety advisor *'didn't know all the positions he needs to get into to'* and that the crotch-strap can often get caught on things, which is *'a hazard'*. Once the crotch-strap was fastened and the safety advisor explained the reason for the crotch-strap being there (to stop the lifejacket not going over your head when it inflates on water impact). After the safety advisor had moved on, I got the opportunity to speak with Paul, who I had met a couple of times before. I asked him how he was getting on and he smiled and said he was *'not bad, just avoiding trouble'*. I laughed and said that it *'looked like he was causing safety some trouble'*, to which he laughed and then responded:

'Yea mate, but you have to admit, Health and Safety is a bit of a joke at times - it goes too far. You wouldn't be able to finish the job without sometimes breaking the rules. You just need to use your own common sense as a risk assessment sometimes... For example, sometimes your gloves are a hazard. They can get stuck on things. So if you're in an area where they might get caught on thing - take them off. Also, your glasses, if they steam up so you can't see clearly - take them off. The other day I was in a confined space with limited mobility and my helmet was restricting vision and getting in my way, so I took it off.'

I asked: *'but what if you trip in the confined space and smack your head?'*

Paul replied: *'well that is your own stupid fault'*.

I said: *'But everyone makes mistakes now and then, no?'*

Paul: *'Yea there is human error, but I've been in construction 40 years and not had a problem.'*

I then asked: *'if he did see someone without an item of PPE on would he challenge them.'*

Paul: *'Na, its nout (nothing) to do with me'*.

The conversation with Paul was enlightening, and not an unusual opinion amongst construction workers on this project. Paul believed that wearing PPE all the time was too generic a rule for all situations, and that sometimes the rules needed to be broken. There were multiple occasions where workers were found not to be wearing their PPE, and this was causing issues with the safety advisors as they constantly had to remind workers to wear their PPE. This problem was noted in a site departmental meeting where the head of department had stated that the lack of PPE compliance was distracting them from the 'real safety issues'.

'Glasses cause more accidents than they stop'

Being a researcher attached to the safety department, I sometimes helped out with safety-related tasks when required. On one occasion I travelled around the site with a safety advisor to put the new monthly safety topic posters up in the workers welfare units. As we walked into a welfare unit, one of the workers noticed the safety advisor and immediately took out his safety glasses. He turned to his fellow worker and said

'I've only had these three days and they are already ----- [explicit language]'. The safety advisor overheard this conversation and asked to take a look. He suggested they might need a clean but the worker disagreed, saying he had just cleaned them and they were scratched. At this point, another worker in the welfare unit interrupted saying they were 'the worst things' and they 'cause more accidents than they stop'. He gave the example, of if they get dirty during a concrete pour, then 'it is not like you have time to go and clean them, and you aren't allowed to take them off'.

'We are delusional. We think we are safe but we are not'

I am not the most comfortable with heights, and have found that the best way to handle this is to not look down! However, on a construction site, sometimes you can't avoid seeing the bottom. As I travelled up the construction hoist with a safety advisor, I was a little nervous. Watching my step from exiting the hoist to scaffold board, I got a quick flash of the drop. However, once on the scaffold I felt more comfortable, as the perimeter was boarded up. There was another higher platform in the centre of the scaffold, which the safety advisor wanted to check. My nerves returned as I climbed the ladder and the boarded perimeter no longer protected my view of the drop. Reaching the top one of the workers opened conversation with: *'you are no good with heights are you?'*. I smiled and said *'was it that easy to tell?'*. He joked *'it sure was, and we are going to enjoy watching you go back down the ladder as well'*. I asked if they were afraid at all of heights, to which they both said they weren't. One of them expanded to say that *'he had been doing it 15 years and always felt comfortable'* and that *'you couldn't do my job if you had any fear'*. While having this discussion, the safety advisor noticed a worker sitting on top of a rebar cage (at height without any protection), smoking and on his mobile phone (both in undesignated areas). He raised these issues with the worker saying *'that is what you could call a hat-trick'* (three safety breaches at the same time). The worker that I had been talking with, then interrupted, saying that with all these safety rules and PPE we think we are safe *'but we are delusional'*. He expanded saying *'what is his helmet going to do for him there? If he falls off the rebar, it will just fall off his head? We think we are safe but we are not'*.

ETHNOGRAPHIC FINDINGS: MIDDLE MANAGEMENT VIEW

'It is just a bit of common sense'

Having heard from some of the operatives on their views on PPE, I was interested to hear from a supervisor for his perspective. I asked a supervisor if his guys wore PPE all the time. He said that most of the time the guys were good and wore full PPE despite not all of them being used to it - some of the subcontractors would turn up without all the required PPE and had never worn some of it before (usually safety glasses). He did admit that there were occasions when the workers would take off items of PPE when they were on site, but not working. He was happy with that arrangement as it was *'just a bit of common sense'*. He expanded to say that if the guys were enforced to wear it all the time it could damage his relationship with them and they would be more likely to take PPE off in other situations that could be higher risk. Though the supervisor did add that when the safety advisor comes out he would make sure that all they guys have their PPE on, *'out of respect to the safety man'*.

'You would be better off trying to understand the behaviours of some of the animals in the zoo than some of my guys'

After reading and signing onto the ten minute brief of a work area, I went to meet the site foreman with one of the safety advisors. I hadn't met the foreman before, so introduced myself as a PhD student researching safety. He asked what part of safety I was looking into and I told him that I was investigating the safety behaviours of the workers. He laughed and said *'you would be better off trying to understand the behaviours of some of the animals in the zoo than some of my guys'*. I asked him what he meant, and he expanded to say that *'some of them just aren't all there'* and they *'often do daft things'*. He said he had this one worker that kept walking into scaffold poles and other objects, and every time he heard *'a yell'* he knew who it was. The same worker once turned up early to start his shift, and proceeded to walk around the site with no PPE on at all. When the foreman confronted him, he believed he hadn't done anything wrong because *'he wasn't working'*. Common sense is based on individual's experiences and perceptions, and therefore can differ between people. This has led to the saying 'common sense is not common' and hence sometimes rules may be required to protect people from themselves.

'There is no such ----- thing as common sense safety in construction'

A minor accident had occurred on site, and during the post-accident investigations a safety advisor was discussing the contributing factors with the site manager. The incident occurred, while extending the cables of the construction hoist. The injured person had put his head over the hoist handrail, while the hoist was moving, to see if any of the cables were snagging. Unfortunately, his head got jammed between the handrail and a cable guide, causing a minor facial injury. One of the scaffolders had said that, even though he had not been trained to complete the task, it should have just been *'common sense'* to not put his head over the edge. The site manager reacted firmly stating: *'there is no such ----- thing as common sense in construction. You try and use that as an excuse and you would be laughed out of court.'*

ETHNOGRAPHIC FINDINGS IN CONTEXT

The following section summarises the above findings, and places them in context with research literature. Two themes appeared to emerge from the findings: common sense versus formal policies and procedures, with specific regard to the blanket rules around PPE; and trust culture versus compensation and blame culture. The safety climate survey highlighted that construction workers wanted a more common sense approach. The ethnographic findings suggested that workers thought all PPE shouldn't be worn at all times, and should instead be task specific. Using a common sense approach would step away from the strict and inflexible site rules, and give the workers more responsibility. This would possibly create more safety aware workers, but some middle managers seemed sceptical whether they could be trusted. A trust culture could be seen as the opposite of a blame culture. The bureaucracy through rules and regulations was unpopular and caused frictions and a lack of trust in relationships. Middle-management acknowledged this but displayed reluctance in adopting a common sense approach, for fear of it being 'laughed out of court'.

PPE: Common Sense vs Formal Policies and Procedures

Many of the construction workers wanted a more common sense approach, which led to a lack of compliance among site safety rules with workers using their own judgement. This lack of compliance led to distractions *'from the real safety issues'* as

emphasis was placed on complying with the rules. Health and safety advisors constantly had to remind workers about PPE compliance. This perhaps suggests a common sense approach would be more appropriate, as this would shift responsibility back to the workers and create a more safety aware workforce. A more common sense approach would result in giving operatives more H&S responsibilities, but some managers displayed a lack of belief in this approach and weren't sure the workforce could be trusted, as they '*often do daft things*'. If operatives were given more freedom for assessing risk and performing some H&S duties, it could be worthwhile performing additional training, since Lombardi *et al.* (2009) found that lack of safety training was an important factor in affecting the lack of PPE use. He also suggested that a lack of comfort/fit and fogging or scratching of eyewear were important barriers to PPE usage, which was also the case in this study. In a common sense approach, such barriers could mean that construction workers could chose not to wear PPE because they don't want to, rather than because they weren't required to. Cameron and Duff (2007) also highlight this issue of PPE comfort as a reason why giving people this responsibility can be inadequate in some instances. In giving such responsibility, they also question beliefs about the risks involved for the task in hand. This could be an important point considering Oswald *et al.* (2014) suggest that due to the types of risks in the construction industry, risks are more likely to be tolerated and under-rated.

Trust Culture vs Compensation and Blame Culture

A compensation culture has created an environment where organisations attempt to eliminate all risks by all means, even though this objective is unattainable (Lord Young of Graffham, 2010; Gyi *et al.*, 1999). This study found this created tensions and frictions in relationships as many workers desired a more common sense approach. Damaged relationships contributed to a lack of trust, thereby contributing to a blame culture. Rather than accepting accidents can and do happen, someone is at fault and financial compensation is perceived to make good of an injury (Lord Young of Graffham, 2010). On this project, researchers found that a blame culture did exist (see Sherratt *et al.*, 2015, in press). This blame culture resulted in a lack of trust between operatives and management to discuss health and safety issues, under-reporting and late reporting. In such a blame culture, there is less opportunity to learn about future accidents. A common sense approach was found to be effective in small and micro firms in a study by Aboagye-Nimo *et al.* (2013), suggesting that this approach could also have value on large projects. However, one key difference is that smaller firms are avoiding this compensation culture for a couple of reasons: the close personal relations in small firms would mean that claims could be seen as a betrayal and there is little money to be gained (Aboagye-Nimo *et al.*, 2013).

In this study on a large project, the managers had a view that a common sense approach could be legally susceptible, and displayed fear of the compensation culture. Gyi *et al.* (1999) found that managers of large construction firms have been affected the most by the compensation culture, and have ended up creating strict rules and regulations in order to prevent such claims from occurring. Simple and inflexible rules may also be perceived as an appropriate approach due to difficulties with communication throughout large organisations. Top-down communication has to travel throughout the whole organisation to the operatives who have no computers access. This issue becomes even more challenging in multinational organisations (see Author *et al.*, 2015, current conference), which is becoming more and more common as the world becomes more globalised. Considering these communication issues, simple strict rules without flexibility could be seen to avoid confusion in a large

organisation. However, this can result in a lack of worker engagement with workers being simply told 'it is a site rule'. Worker engagement is often perceived as a measure of trust (HSE, 2012). Researchers found that the Olympic Park project managed to counteract blame through worker engagement and trust (HSE, 2012), highlighting that it can be achieved in large organisations. Strict rules and regulations with little flexibility tend to the most basic stage of a five-stage worker engagement process documented by the HSE (2011): 'Individuals are simply told what to do regarding safety and/or health.' This means that decisions are not fully explained to workers, workers are not involved in the decision making process and are not trained to perform some small day to day H&S duties etc. A lack of engagement can result in a lack of compliance, resistance to the rules and a divide between management and the workforce.

CONCLUSIONS

Previous research has found the common sense approach to be effective in small construction firms. However, there is a lack of the compensation culture in such small firms in comparison to larger organisations, which means that larger firms adopting this approach could be more susceptible to claims. This has led to excessive health and safety measures, and evidence in this study suggests that there was resistance to such measures, especially from those at operative-level. This can lead to negative consequences such as resentment, poorer relationships and a divide between operatives and management. Using a common sense approach gives workers more responsibility and flexibility, but some managers didn't think that workers could be trusted and that it would leave the firm open to legal action. While a compensation culture exists, a common sense approach may be more difficult to implement and large firms may have to adopt strict regulations. This can lead to negative consequences and a blame culture, which creates an environment where it is hard to learn about future accidents. Trust can be seen as the opposite to blame and is often perceived as a measure of worker engagement, which highlights the importance of involving the workforce in H&S decisions. While worker engagement can be more challenging in a large organisation due to size and communication channels, large organisations should realise its importance in attempting to avoid overcome poor operative and management relationships and a blame culture.

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FACTORS THAT AFFECT CONSTRUCTION SAFETY EQUILIBRIUM: NAKHON RATCHASIMA CONSTRUCTION CREWS PERSPECTIVE

Nart Sooksil¹ and Vacharapoom Benjaoran

School of Civil Engineering, Institute of Engineering, Suranaree University of Technology, Nakhon Ratchasima 30000, Thailand

Mostly construction workers' behaviours are shaped by task objective constraints and their capability during operating the task. Their behaviours seem to be a systematic migration toward to the boundary of functionally acceptable performance. It is forced by management pressure and an effort gradient of worker. This circumstance brings those workforces to the error margin and finally ends up with the accident. This research presents the Construction Safety Equilibrium Model (CSEM) which provides a balance between task demand (TD) and capability (C). The author investigated the factors that affect task demand and capability via Delphi process. The sample group was represented by 18 employees from various construction projects in the north-east province of Nakhon Ratchasima, Thailand, holding positions of civil engineer, safety officer and foreman. Results of the analysis showed that 1) the most significant factors of task demand were tools factor, work quality strictness factor and work pacing factor. The least significant factor was the physical site condition factor; 2) for capability; the highest significant factors were foreman communication ability factor, worker health condition factor and foreman work experience factor. Apart from that, the job training factor was the lowest significant factor. Regarding these results, both of the lowest significant factors from task demand and capability occupied the median value over 1.5 which meant that all 35 proposed factors remained.

Keywords: capability, construction safety, safety equilibrium, task demand.

INTRODUCTION

Construction work involves a lot of work processes which are subjected to change according to project-specific requirements and context. Moreover, the work environment is also change abruptly as dynamic condition. These changes create many chances of accidents and raised statistical number of construction trade occupational injuries (SSO 2013), (BLS 2012), (Haslam *et al.* 2005).

Human resource is the main workforce needed in the construction industry to accomplish its target. However, the results from Haslam *et al* (2005) research found that the main causal factor in construction accidents were problems arising from workers and brought into concern of worker behaviour while performing tasks. Their behaviours lead to risky conditions brought on by management pressure and their efforts often leads to an accident.

The less chance of risky conditions are beneficial to the construction trade. Thus, the risk condition will not occur as long as the construction projects have the effective

¹ d5640331@g.sut.ac.th

human resource management to deal with dynamic circumstances by assigning the right resource to the right task concerning safety and efficiency.

The present paper proposed the construction safety equilibrium model between task demand and worker capability could explain workers' behaviour tend to move into the risk condition. The Delphi Process has been applied to study the significance of the proposed factors for both task demand and capability. The least significant factors which received the median value below 1.5 (out of 5.0 scale) will be removed from the proposed model. The remaining significant factors will give consideration to classify the priority factor for practical purposes.

WORKERS' BEHAVIOURS DURING WORKING

Rasmussen (1997: 189) explains how the workers' behaviours tend to migrate closer to the boundary of functionally acceptable performance *"Human behaviour in any work system is shaped by objectives and constraints which must be respected by the all for work performance to be successful. However, aiming at such productive targets, many degrees of freedom are left open which will have to be closed by the individual worker by an adaptive search guided by process criteria such as work load, cost effectiveness, risk of failure, joy of exploration, etc. The work space within which the human workers can navigate freely during this search is bounded by administrative, functional, and safety related constraints. The normal changes found in local work conditions lead to frequent modifications of strategies and activity will show great variability. Such local, situation-induced variations within the work space call to mind the 'Brownian movements' of the molecules of a gas. During the adaptive search the workers have ample opportunity to identify 'an effort gradient' and management will normally supply an effective 'cost gradient'. The result will very likely be a systematic migration toward the boundary of functionally acceptable performance and, if crossing the boundary is irreversible, an error or an accident may occur."* As illustrated in Fig.1.

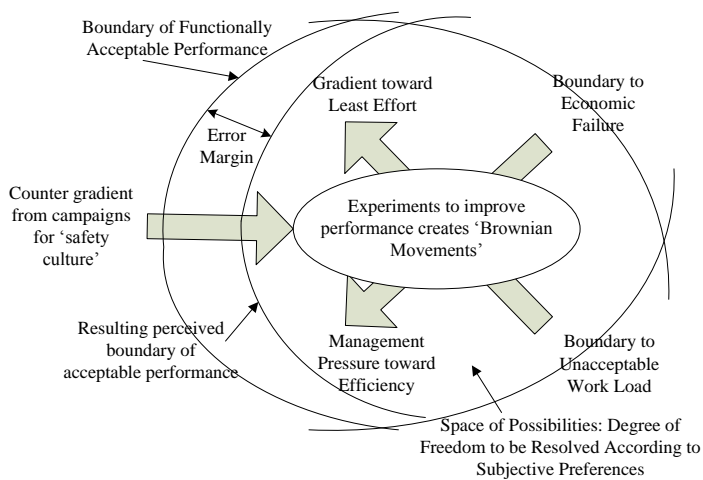


Figure 1: Rasmussen's work behaviour model (adapted from Rasmussen 1997)

Rasmussen's principle is grounded in Cognitive System Engineering: CSE which is concerned with the characteristics of the work system (the features of the task, tools, and work context) that influence the decisions, behaviors, and the possibility of errors and failures (Fuller 2005). Most applications of CSE to safety management are related

to high-risk operations in complex systems such as aviation, health care, and nuclear and chemical plants. In the area of construction safety, Saurin *et al.* (2007) has implemented and examined site safety practices from a cognitive perspective.

Construction is a loosely coupled work system and leaves many degrees of freedom for the worker crew (Mitropoulos *et al.* 2009). It is only a suggested workflow but isn't required to follow the steps which left some spaces for the workforce to consider a appropriate choice of working decisions under dynamic situation (Saurin *et al.* 2008). These situations bring the workers' behaviour migration closer to the boundary of functionally acceptable performance and working in the boundary of error margin.

The implementation of safety rules and safety campaign in the construction trade is mostly prescribed "safe behaviour" (Mitropoulos *et al.* 2005) to keep workers' behaviour away from the boundary of functionally acceptable performance, however, the applied pressures are still pushing workers toward that boundary. Moreover, the development of construction technology and construction safety has been improved (Everett 1999), thus, human adaptation compensates for these safety improvements. This phenomenon has been observed in traffic research and explains why technological safety improvements have not generated the expected improvement in safety (Fuller 2005).

APPLIED TRAFFIC ACCIDENT MODEL IN CONSTRUCTION

The characteristics of traffic change all the time, this dynamic circumstance is similar to the changes in construction and it is supported by the study of road accidents in Fuller (2005) research. With Fuller's study (2005), Mitropoulos and Cupido (2009) have applied this principle in construction trade as well.

With regard to traffic accidents, the Task Demand-Capability Interface (TCI) model (Fuller 2005) provides a new conceptualization of the process by which collisions occur. At the heart of the TCI model is the relationship between the task demand and the capability applied to achieve a safe outcome while driving the vehicle. When the task demand is less than capability, the driver has control of the situation. Whereas, when the task demand is greater than the applied capability, the result is loss of control, which may result in a crash (or may not, if there is a compensatory action by others). The TCI model is illustrated as Fig.2.

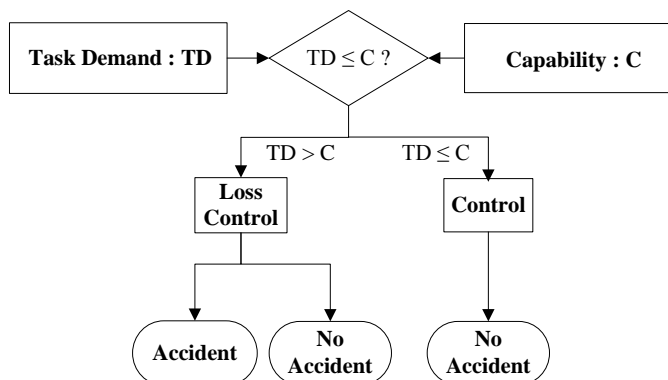


Figure 2: The Task Demand -Capability Interface model (adapted from Fuller 2005).

Task demands are determined by factors related to the vehicle, the road, the traffic conditions, the speed, and other tasks that the driver may perform. The driver's speed has a central role in safety and is affected by the driver's goals (such as minimizing time to arrival), as well as motives inherent in human behavior, such as maintaining

speed and conservation of effort which makes the task demand not too high and can be paired with the low capability of the driver.

The applied capability relies on the driver's competence (training and experience), the level of activation, and human factors (fatigue, etc.). The level of task demand and capability changes over time, as both the driving conditions and the capability-related factors change. Moreover, task demand and capability are interdependent - changes in the perceived task demand change the driver's level of activation and consequently the capability. Thus, to maintain control, it is essential that the driver has effective anticipate to correctly assessing of the task demands.

In the experiment, the volunteers have to assess both task difficulty and statistical risk directly by viewing video sequences of roadway segments, filmed from the viewpoint of the driver, and travelling at different speeds. Participants were required to rate each sequence for task difficulty and for statistical risk of collision. The results found that speed was the driver's choice to control the difficulty level and balance the task demand with driver capability.

CONSTRUCTION SAFETY EQUILIBRIUM MODEL: CSEM

The proposed CSEM is synthesized from Rasmussen's (1997) study which explains the workers' behaviour migration toward the boundary of functionally acceptable performance and principle of traffic accident proposed by Fuller (2005). The CSEM was not based on unsafe acts and unsafe conditions as suggested by previous construction safety models but described individual workers' behaviour that adjusted to fit with task demand and capability in each circumstance.

Using the construction safety equilibrium principle to explain accident situations.

With regard to Fuller's principle (2005), traffic accidents that occurred due to task demands exceeding the driver's capability thus creating uncontrolled situations. The Rasmussen (2007) principle claimed that the workers' behaviour always migrates toward the boundary of functionally acceptable performance which is driven by 2 main pressures. The first is management pressure comparable to the task demand. The second pressure is the work effort comparable to worker's capability. Whenever the task demand is greater than capability at that moment in time becomes the risk condition and creates the possibility of an accident.

For the proposed construction safety equilibrium principle, accidents will occur when workers are in the risk condition which the task demand is higher than capability and caused by either worker error or changes in working condition (Mitropoulos *et al.* 2005). There will not necessarily be an accident every time when workers are in that situation, but there is a possibility of an accident.

From this perspective, errors are defined as unattended actions that fail to achieve their intended outcome. Reason (1990) classified human error in three types: slips (unintentional loss of control), mistakes (selection of incorrect course of action) and perceptual errors. In the case of working among the risk condition with an error, this error pushes worker to reach boundary of loss control and ends up with an accident. If the worker can timely detect the error, that circumstance will become a controlled condition again.

For accidents caused by changes in working conditions such as losing soil stability abruptly, if the worker has the ability to react fast enough to avoid the event, then the

incident is a near miss. In the event that the circumstance is very sudden, there is no time to react. Workers experience and situational awareness are needed.

The proposition of construction safety equilibrium model.

The construction safety equilibrium model develops with three key propositions:

1. Consideration for the task demand and capability are based on the working context to succeed in the intended outcome rather than in the working safety context, then matching the task demand level with capability level that were assessed from comprised factors in CSEM. This method will eliminate the conflicts among production and safety; in the short term these conflicts are usually resolved in favour of production (Reason 1990).

2. Construction accidents occur from task demand exceeding capability and result in various impact levels, this impact level depends on the difference between TD and C. The author proposed 5 impact levels, these impact levels are based on consideration of individual physical worker impact, not on property impact or other losses. The author assessed the lost work days of the injured workers and interpreted the cost by the daily wage of each worker.

3. This construction safety equilibrium model is a quantitative safety indices model rather than a qualitative model which safety and risk dimensions are very often taken seriously in some circles only when numbers or equations are illustrated (Le Coze 2015).

Principle of construction safety equilibrium model.

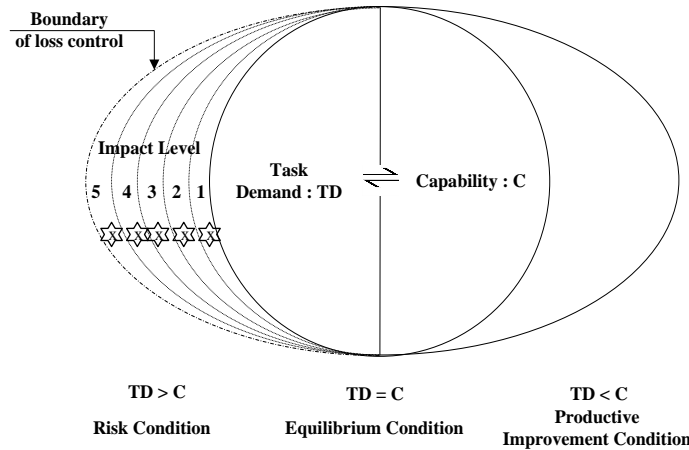


Figure 3: The construction safety equilibrium model : CSEM.

CSEM is the balance between task demand and capability as shown in fig.3. The conceptual framework displayed confirms the incident will not happen if the task demands equal capability and creates the equilibrium condition. And there would be no chance of accidents if the worker’s capability is more than the task demand and the chance of productivity improvement are emerged. If the task demand is greater than the worker’s capability, this puts that worker into the risk condition with the possibility of an accident. Whenever the mishap happens, it has an impact and varies by the difference between TD and C.

$$\text{Task Demand} - \text{Capability} = f(\text{Impact Level}) \tag{1}$$

The impact level was analyzed by the difference between task demand and capability as computed by Eq. 1. The author proposed the impact level in 5 levels from very low, low, medium, high and very high. These impact levels are formed by the lost hours (in term of cost) and based on the assumption that each worker gets a different daily wage and depends on each worker's capability, therefore the same lost hours will have various values. Hence, the author proposed the impact level scale in terms of the lost work hours and interpreted this to cost as shown in table 1.

Table 1: Proposed impact level scale

TD - C	Impact Level (Baht)
0.01 - 0.20	Very Low (0 - 300 ฿)
0.21 - 0.40	Low (301 - 1,000 ฿)
0.41 - 1.50	Medium (1,001 - 10,000 ฿)
1.51 - 1.75	High (10,001 - 1,000,000 ฿)
1.76 - 2.00	Very High (> 1,000,000 ฿)

As previously mentioned, when the task demand becomes greater than capability, it also means that the assigned task is too difficult for workers to perform their jobs and brings the workers into the risk condition which will have a likelihood of an accident. Even if the accident does not happen in that situation, this would be a period of low production and high risk. In contrast with the case where the task demand is less than or equal to the capability, that task has zero chance of accident as it is a controlled condition. By the time that task demand is lower than capability, this task is easier for workers to perform and has the potential to improve productivity as well.

Prevention strategies by construction safety equilibrium principle.

The prevention strategies according to the construction safety equilibrium principle are maintaining the balance between task demand and capability under the concept of "matching the right man to the right job" and ought to have more value on the capability side in the event that workers' behaviour tended to migrate closer to the boundary of functionally acceptable performance (Rasmussen 1997). These workers' behaviour will increase the value of task demand as workers try to work more efficiently due to management pressure. In this situation, there is a need for error management and situation awareness strategies to prevent the accident (Mitropoulos *et al.* 2005).

DETERMINATION OF TASK DEMAND AND CAPABILITY FACTORS BY DELPHI PROCESS

After presenting the construction safety equilibrium model, the author introduced the determination of task demand and capability factors via the Delphi process. The Delphi method is a systematic and interactive research technique for obtaining the judgment of a panel of independent experts on a specific topic. Individuals are selected according to predefined guidelines and are asked to participate in two or more rounds of structured surveys. After each round, the moderator provides an anonymous summary of the experts' input from the previous survey as a part of the subsequent survey. In each subsequent round, participants are encouraged to review the anonymous opinion of the other panelists and consider revising their previous response. The goal during this process is to decrease the variability of the responses and achieve group consensus about the correct value (Hallowell and Gambatese 2010). Delphi is intended for use in judgment and forecasting situations in which pure

model-based statistical methods are not practical or possible because of lack of appropriate historical /economic/ technical data, and thus where some form of human judgemental input is necessary (Rowe and Wright 1999).

The author used the adapted Delphi process on the data collection phase by adding the group meeting method to shortening the length of the whole process. During the data collection phase, it was determined the proposed factors from literature reviewed of Mitropoulos and Cupido (2009), Haslam *et al.* (2005) Loughborough University and UMIST (2003). These proposed factors are concluded in the research by Sooksil and Benjaoran (2014). Furthermore, the author also added the results from the preliminary survey about the task demand factor and capability factor from the group of construction safety experts in high-rise construction projects in Bangkok, Thailand into the proposed factors as well. The participants who participated in determination factor by the Delphi process were 18 employees from various construction projects in the north-east province of Nakhon Ratchasima, Thailand. This province ranked first in number worker injuries and ranked in the top 3 for high injury rate per 1,000 full-time equivalent workers of the north-east region (SSO 2014). These 18 employees held engineer, safety officer, and foreman positions. They have been considered the significant of 23 task demand factors and 12 capability factors. The summary of determination factors that were used via the Delphi process are as follows:

- 2 rounds of surveys.
- After finishing each round, the moderator has given the group median of the previous round to participants before continuing to the next round.
- Some factors will be removed if it's received the group median below 1.5.
- The purpose of the process is to achieve a group consensus by examining the group quartile range, if less or equal 1.5 the process is ended.

RESULTS OF DETERMINATION FACTOR BY DELPHI PROCESS

The results of the determination factor by the Delphi process represented by 18 construction employees in Nakhon Ratchasima Province are shown in table 2 and 3.

Factors that affect task demand.

The completed determination process by the Delphi process found that none of the 23 factors (TD1-TD23) were removed because the group median was more than 1.5. In the 1st round of Delphi process, the median of all groups was higher than 1.5, but still didn't achieve group consensus by the 4 factors which their quartile range was over 1.5 and continued to the 2nd round survey. Before starting the 2nd round, the moderator provided the prior group median to the participants. For the 2nd round, the entire group median was still higher than 1.5 and the group consensus was not achieved by 2 out of 23 factors, unfortunately, due to the restricted data collection time, the process was stopped in 2nd round. (By the way, the author knows that all 23 factors have definitely not been removed.)

The highest group median was TD7: tools factor, which the sample group had been considered as the most influential factor to the task demand and made the task more difficult to perform as expected outcome most (group median = 4.22). The runner up was TD11: Work Quality Strictness factor that is controlled by the owner of construction project made more of an impact to task demand with 4.00 groups median. In third place was TD18: Work Pacing factor with 3.94 of group median. The increased pace made work more difficult which is similar to the study of traffic

accidents which claimed that speed was the driver's choice to control the difficulty level (Fuller 2005). The least impacted factor was TD13: Physical Site Condition factor with 3.04 group median. The participants believe that most construction projects in Nakhon Ratchasima Province are not limited with physical site condition like those found in Bangkok.

Table 2: Determination results of task demand factors by the Delphi process.

Categorised Factor	Factor	Round 1		Round 2	
		Median	QR <= 1.5	Median	QR <= 1.5
Task Factor	TD1 Task Complexity	3.69	1.11	3.67	1.03
	TD2 Transportation of Material	3.33	1.19	3.35	1.03
	TD3 Work Co-ordination	3.25	1.03	3.35	1.03
	TD4 Working Area	3.69	1.18	3.67	1.10
	TD5 Type of Main Material	3.25	1.03	3.25	1.03
	TD6 Machine/Equipment	3.81	1.14	3.81	1.14
	TD7 Tools	4.19	1.14	4.22	1.04
	TD8 Designing	3.60	1.42	3.80	1.54
	TD9 Construction Method	3.58	1.33	3.57	1.15
	TD10 Engineering Criteria Strictness	3.71	1.21	3.71	1.21
	TD11 Work Quality Strictness	4.00	0.94	4.00	0.94
Environment Factor	TD12 Weather Condition	3.86	1.31	3.86	1.26
	TD13 Physical Site Condition	3.00	0.65	3.04	0.61
	TD14 Site Tidy, Cleanliness and Sanitation	3.25	1.51	3.43	1.30
	TD15 Work Obstacle Condition	3.29	1.21	3.44	1.06
	TD16 Site Welfare	3.81	1.43	3.89	1.05
	TD17 Society and Environment Impacted	3.14	2.11	3.31	1.87
	TD18 Work Pacing	4.00	0.94	3.94	1.12
Work Behaviour Factor	TD19 Safety Rule Strictness	3.60	1.89	3.75	1.42
	TD20 Group or Individual Work	3.63	1.78	3.63	1.69
	TD21 Work Hour Restricted	3.33	1.19	3.35	1.03
	TD22 Number of Commander	3.40	1.49	3.56	1.06
	TD23 Abrupt Change of Working Method	3.71	1.28	3.89	1.01

Factors that affect capability.

None of the 12 factors (C1-C12) from capability were removed. In the 1st round, all group medians were higher than 1.5 and still did not achieve the group consensus by 3 factors and continued to the 2nd round with the informed prior group median. For the 2nd round, the entire group median was still higher than 1.5 and the group consensus was achieved with the process stopped.

The top 3 highest group medians were C12: Foreman Communication Ability factor, C3: Worker Health Condition factor, and C11: Foreman Work Experience factor with group medians of 4.73, 4.35 and 4.33, respectively. The overall outcome from the sample group found that the main influence factor of capability was mostly in the foreman categorized factor which is reflected in the situation upcoming workforces from neighbouring countries to each province of Thailand that will need a competent foreman to supervise these workers. The lowest group median factor goes to C2: Job Training factor with 3.56 due to the fact that most construction workers are foreigners, so construction companies are less motivated to provide job training.

Table 3: Determination results of capability factors by Delphi process.

Categorised Factor	Factor	Round 1		Round 2	
		Median	QR <= 1.5	Median	QR <= 1.5
Competence Factor	C1 Work Experience	3.95	0.85	4.04	0.71
	C2 Job Training	3.75	1.35	3.56	1.00
	C3 Worker Health Condition	4.29	1.21	4.35	0.97
Human Factor	C4 Hasten Behaviour	3.75	0.97	3.79	0.80
	C5 Fatigue	4.11	1.01	4.27	0.91
	C6 Frustration	3.60	1.89	3.92	1.50
	C7 Job Satisfaction	3.75	1.51	3.86	1.26
	C8 Working Relationship	3.86	1.40	3.86	1.31
Attention Factor	C9 Work Attention	4.00	1.53	4.25	0.97
	C10 Safety Awareness	4.11	1.01	4.15	0.93
Foreman Factor	C11 Foreman Work Experience	4.31	1.11	4.33	1.03
	C12 Foreman Communication Ability	4.65	1.03	4.73	0.91

CONCLUSIONS

The purposes of the current study was to present the principle of construction safety equilibrium, determine task demand factors and capability factors by 18 employees who were working in construction projects in Nakhon Ratchasima Province. The main conclusion is as follows;

The principle of construction safety equilibrium considers task and worker separately, and then employs the principle of matching the right man with the right job and then this situation will create the equilibrium condition between task demand and worker's capability. Consequently, the person in charge can perform the task productively without any accidents.

The results of the determination factor by 2 rounds of Delphi process indicate that none of 35 factors from task demand and capability were removed. These 35 proposed factors came from reference studies and the preliminary surveys of high-rise construction safety experts in Bangkok, Thailand. By the way, the median value of each factor can bring benefits to practitioners by prioritise those factors as their shown significance and it provides practitioners with strategies to assign the right worker to the suitable task.

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IS THE CONCEPT OF ZERO HARM AN ACHIEVABLE GOAL?

Brianna Chesworth¹

Ampcontrol, Mackay, QLD 4740, Australia

The concept of zero harm is widely accepted to be the social norm across many industries; providing organisations at least with the 'opportunity' to go "*beyond simple compliance*" and into the realm of "*business sustainability*". Achievability of these opportunities however is dependent on the workforce's capacity to successfully work under what is simply a well-branded slogan. Dependence on Zero Harm success at such a level creates for organisations a disconnection between management reporting and workforce performance driven by the quantifying of key performance indicator data. Viewing the Zero Harm concept through social constructivism provides an opportunity to explore the issues present rather than simply quantifying them. A case study approach utilising an inductive open-ended interviews strategy was used to explore the organisational relationships present within a construction company participating in a zero harm workplace. The approach assists in understanding what drives the collection and analysis of safety data and programming and the capturing of performance. Findings from the case study demonstrate that organisational expectations influence the overall Zero Harm approachability.

Keywords: case study, constructivism, organisational culture, safety performance, zero harm.

INTRODUCTION

Within Australia many leading companies utilise a 'Zero Harm', 'Zero Target' or 'Zero Goal' safety centric branding as a way to sell their commitment to workplace health and safety. A specific 'Zero' message that is continued across internal/external documentation, site hoardings, presentations and websites and a trend shared in other countries (Sherratt, 2014). For some companies this branding is supported by ongoing compliance to and certification of Health and Safety Management systems via AS/NZ 4801 and ISO 18001 (Reynoldson, 2008). Compliance to an organisational Safety Management System and system certification provides organisations with a justifiable reason to disconnect between providing the workforce with a manageable and user-friendly system (or perceptions) and a simplistic yet popular safety system branding (or attitudes) that ultimately form a safety culture (Reichers and Schnedier, 1990; Clarke, 2006; Mayze and Bradley, 2008).

The increasing popularity of the branded health and safety system is cause for concern, as it puts undue pressure on employees to perform their normal duties guided by unrealistic expectations (Reason, 1998; Cooper, 2002); further complicating organisational reporting capabilities and systems. The current industry trend is to promote the reporting of all incidents thus establishing a working environment that is safety empowered and proactive (DuPont, 1995). Underlining this empowered and

¹ Brianna.Chesworth@ampcontrolgroup.com

proactive workforce is the expectation that what is reported will not be used to warrant retribution for the worker or the site, although this is not always the case (Taylor, 2002). Sherratt (2014) highlighted this focusing on the utopian and dystopian interpretations of 'Zero' vision programming in Scandinavian construction and the overarching tangibility of measurement and commitment to 'Zero' vision within UK construction (Jacoby, 2005).

The paper aims to explore the adoption of Zero Harm as part of a construction organisation's overarching Health and Safety management system. It will examine individual and group perceptions as well as awareness of the management, monitoring and performance of the system and conceptual achievability. Of particular interest is the role safety KPIs (key performance indicators) in understanding achievability across the organisation and how attitudes towards KPIs influence organisational culture.

THE CONCEPT OF ZERO HARM

A Need to Change

It is well documented that Australian construction has a poor safety record, injury and fatality rates are the 4th highest (17 per 1000 employees) across all industries (Workplace Relations Minister's Council, 2014). McCarthy and Hampton (2008) identified a number of factors contributing to Australia's poor safety record such as ongoing high rates of labour and subcontractor movement between companies, sites and projects and a lack of consistency in industry-wide acceptance of safety compliance. Despite an awareness of contributing factors, there has been minimal improvement in the type of recordable incidents.

To better understand industry awareness and monitor performance The Workplace Relations Minister Council led Australian Work Health and Safety Strategy 2012–2022 and subsequent yearly Comparative Monitoring Reports have established key reporting KPIs to assist in the assessment and benchmarking of performance. Although, typically these reports simply provide an awareness of construction performance comparative to quantitative requirements such as worker compensation claims, safety compliance and enforcement activities, without considering the subsequent awareness of safety within the organisation (Reynoldson, 2008). As Australian construction continues to move into the next decade the concept of zero harm is becoming more prevalent in safety management plans as organisation's attempt to provide workers, with a “*consistent and clear message that safety is critical*” (McCarthy and Hampton, 2008).

Increased awareness of the Zero Harm concept across the construction industry can be attributed to improving safety performance and programming in the mining industry going beyond compliance and toward better financial performance (Ekevall, Gillespie and Riege, 2008). The concept of zero harm emerged in the late 1990's in mining and was seen as a means to simplify already over complicated safety management systems. Companies believed a KISS approach (Kiss It Simple Stupid) would assist in promoting leadership qualities, better workplace conditions and behaviours as well as a proactive culture (Reynoldson, 2008; Dupont, 1998). The decision by mining companies has inadvertently impacted the Australian construction industry as more companies look for work in non-traditional construction fields as means to stay competitive (Ekevall, Gillespie and Riege, 2008).

Much has been discussed about Zero Harm and the positive characteristics that a simplistic approach brings to any organisation (Ekevall, Gillespie and Riege, 2008; Herbertson, 2008; Reynoldson, 2008). Central to the adoption of the Zero Harm concept is a need to review and understand the social aspects of the organisation, a view proposed by Agnew and Snyder (2002). Leadership is a central strategy of the Zero Harm movement which seems to allow organisations the ability to change already existing safety management systems without impacting too heavily on the social aspects present within the organisation (Cooper, 1998; Herbertson, 2008; Reynoldson, 2008; Spigener, 2009). Underpinning the leadership approach is the development of organisational business standards and policies, linked to procedures, practices and behaviours, which is supported by both systems and people (i.e. leadership) that then lead into the Zero Harm concept (refer to figure 1 Road to Zero Harm). Within Australia this road map is adopted by a number of companies and used as a means to not only drive zero harm but also as a means to continually evolve their subsequent safety management systems (Ekevall, Gillespie and Riege, 2008). Although a program driven by leadership can only provide so much substance.

The problem that is prevalent within industry is that there is not one true representation of Zero Harm. Rather the language, metrics and rhetoric of Zero Harm is concerned about the counter argument to the already consultative and collaborative safety management system (Jones, 2012).

The Zero Harm Environment

The fundamental application of Zero Harm is similarly represented across the construction industry and is aligned to the overarching commitment to health and safety of employees, contractors and visitors (Herbertson, 2008). The structured approach of the Health and Safety Management system within any workplace enables for a certain level of performance management, managed through key performance indicator data (Safe Work Australia 2012).

Demonstrated commitment is typically represented through the implementation and continuous improvement of the overarching Health and Safety Management system. The system provides a central standard for the management of health and safety issues, and applies to all units across all sites and business activities (Zou and Sunindijo, 2015). Within the system the roles, responsibilities and accountabilities are clearly defined, with workforce participation to be demonstrated through specific reporting lines.

The differing application being Zero Harm models being developed to create proactive cultures, overcome existing prevailing cultures and to foster shared values (for example, Holcim; Taylor Rail; Leighton Holdings; Siemens; BMD; Downer Group).

The Zero Harm Pledge

The Zero Harm commitment ultimately is of differing representation and is typically influenced by the nature of supply chain relationships present in contractual agreements (Ormond, 2014). A google search of Australian construction contractors working closely with mining companies identified 45 of 60 companies currently working within construction delivering Engineering, Procurement and Construction (EPC) services as upholding the Zero Harm concept as part of their ongoing safety commitment.

The rapid uptake of Zero Harm branding in construction has been identified as a serious cause for concern, due to the cynical nature of the construction industry and the level of commitment by an organisation to essentially change the way things are done (Ekevall, Gillespie and Riege, 2008). The impact on the workforce, who the health and safety management system is designed, lacks the clarity that is required when a paradigm shift to the system occurs (Herbertson, 2008; Jones, 2012).

The Problem

In its current form Zero Harm is representative as little more than a vision, a philosophy, a commitment or a short term goal to ensure ongoing work (Jones, 2012). What is unclear and an underlining issue is the concept's applicability within a multi-level workplace environment, although there has been some debate within academia regarding application at site level (Sherratt *et al*, 2011, 2012; Sherratt, 2013, 2014), concept measurement (Mayze and Bradley, 2008) and leadership (Herbertson, 2008; Reynoldson, 2008).

This paper explores the fundamental approach and application of a construction organisation making the decision to implement a Zero Harm safety programme. The exploration of zero harm's fundamental application within an organisation is central to understanding the purpose, structure and the culture in which the concept exists.

METHODOLOGY

The central theme to the paper is perception, therefore a constructivist approach is considered (Denzin and Lincoln, 2009; Bryman, 2008). The constructivist nature of the paper examines the different perceptions, awareness and discourse present within an organisation during adoption; further allowing a focus on understanding the issues rather than the quantifying of safety achievements.

Data was collected via 8 face-to-face interviews and 2 focus groups (up to 8 participants) over a 8 month period, incorporating the decision, implementation programme and initial roll-out. The purpose of interviews and focus group was to provide a multi-layered perception and awareness of the zero harm concepts and the organisational culture, as were as follows:

- Corporate WHSEQ perspective - 3 interviews conducted across head office and the focus site (Interviewees 2, 4 and 8);
- Management and site perspective - 5 interviews conducted across head office and the focus site (Interviewees 1, 3, 5, 6 and 7);
- Worker perspective - 2 focus groups conducted with the focus site (FG 1 and FG 2).

Secondary documentary data including roll out packaging was also analysed as means to understand the communicative methods in practice within the organisation. This approach allows triangulation of the research across data sources and emerging key themes to be assessed (Potter and Wetherell, 1992). The data was analysed utilising a thematic analysis framework to identify similar themes of core concept awareness and recognition of the agenda underpinning supplementary documentary data (Boyztis, 1998; Silverman, 2006). The results are presented in a case study format, further providing the opportunity to analyse holistically the literal and theoretical replication between that is or may be present between organisation groups (Flyvbjerg, 2006; Yin, 1994; 2013). The results highlight a clear lack of perceptible awareness from the leadership team driving the 'Zero Harm' adoption, which is a direct contrast to the

themes presented in existing safety research (Lardner, 2002; Mayze and Bradley, 2008; Herbertson, 2008; Reynoldson, 2008).

FINDINGS AND DISCUSSION

Participants were asked a series of closed and open-ended questions addressing their understanding and awareness of the:

- Organisational environment;
- Zero harm concept; and
- Safety Culture.

These interview topic areas form the main themes of the findings and discussion.

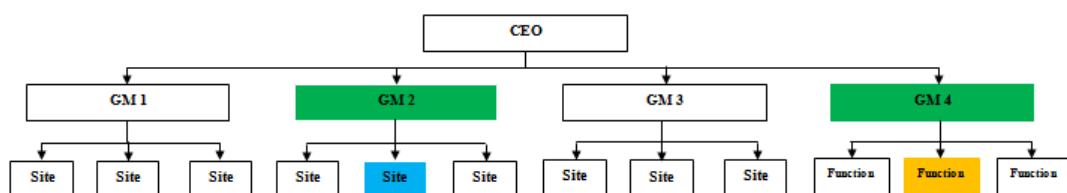
The Organisational Environment

The organisation is an international construction company providing electrical engineering, procurement and construction (EPC) capabilities; providing services across all major Australian markets incorporating infrastructure, mining, residential and commercial. Within the organisation the safety culture is underpinned by a simple motto providing employees with a simplistic understanding of the overarching safety commitment.

The bureaucratic structure of the organisation (as shown in Figure 1 Organisation Structure) highlights a clear leadership disconnection between operational functions and the operating sites. The selected site is located in Queensland Australia and is involved in providing support capabilities for engineering, procurement and construction as well as operational support during commissioning. The GM of this site is based at the NSW head office travelling to the site once every 6 months. All sites operating within this region are supported by 1 functional advisor who directly reports to the state manager while indirectly reporting to the functional group manager.

Within the WHSEQ function all team members are located at head office or within 100km of head office. The location of the WHSEQ team highlights a clear physical disconnection which can influence the fundamental application of Zero Harm within the organisation. One might consider this physical separation to be a key factor in the un-achievability of Zero Harm.

Figure 1: Organisation Structure



Strong and central leadership has been often discussed as a core requirement for successful adoption of zero harm (Reynoldson, 2008; Herbertson, 2008; Elvisker, 2008). Leadership is not just representative of top-down relationships but also from the bottom-up, within safety it is encouraged to have leadership driven by the workers rather than management (Dupont, 1995); although management still provide set guidelines. The organisation is in a difficult position in terms of their ability to achieve a zero harm lead safety culture; due in part to the organisation being underpinned by a complex management structure. The organisational structure is driven by a bureaucratic style of management, characterised by silo like

communication channels representative by 5 divisional senior management leaders managing up to 8 separate sites across those 5 divisions. Problems occur in the spread of the WHSEQ function across those sites led by 4 personnel in advisory roles tasked with the responsibility of ensuring compliance to the overarching reporting system as developed by the function. The organisation has 3 senior WHSEQ representatives who rarely visit satellite sites, managing the reporting from the corporate head office. The bureaucratic structure of the organisation promotes a reporting environment that is typically reactive in its ability to commit to ongoing reporting capabilities; made worse by the lack of involvement from senior management and WHSEQ representatives as illustrated by discussions with worker focus groups (group 2):

“.....we continually get told we need to be doing and doing this without impacting zero safety targets, but we don't get proper support from WHSEQ. It's difficult when we get blamed for not following instructions...”

The focus group here is highlighting a clear dependence on the top-down leadership approach, highlighted by the group's use of getting told what they need to do. They see corporate as setting the practices, but do not see that site management is responsible for the communication and supporting of set instructions. To the workforce it is seen that the WHSEQ team don't do enough to support sites as system changes occur, this is representative of the 'blame' the workforce experiences. The emphasis on 'zero harm safety targets' highlights a disconnection between the basic concept of zero harm, the setting of KPIs and monitoring of 'zero harm safety targets' at a site level.

The Zero Harm Concept

Byard (2009) describes the application of zero harm concepts as a widespread adoption of a zero goal, zero incidents, zero accidents and zero tolerance. A zero goal that is ultimately unsustainable and unachievable. Despite the complex organisational structure a simplistic safety programme is present; the organisation promotes a Stay Safe message aligned to a Zero Harm safety programme.

The safety message forms part of the organisation's branding; externally Zero Harm is branded as a holistic approach underpinned by daily life and established and certified to Health and Safety Management Systems (AS/NZS 4801, ISO 18001). A view illustrated by the IMS manager (interviewee 2):

“...the organisation committing to the motto and the ongoing reporting and auditing of the systems...and is represented through overarching work health and safety policies...”

As well as the WHSEQ group manager (interviewee 4):

“...individuals are more likely to report and utilise a system which is easily accessible and designed around the lowest common denominator...”

The two managers of the system place the achievability of Zero Harm at the core of the organisation, achieved not only through the active participation of employees and their use of the system but also via certified compliance to overarching Health and Safety Management Systems. Central to the concept within the organisation is the transferring of responsibilities from management to the individual worker a view that is representative in recent changes to Workplace Health and Safety legislation in Australia. Although underlining message within the organisation is safety is about protecting yourself and your mates.

The tangibility of achievement for the organisation is managed through specific site reporting capabilities set by the WHSEQ function. The organisation utilises a number of key performance indicator reporting platforms such as toolbox talks, safety alerts and bulletins and monthly reporting as well as senior and frontline leadership metrics to monitor performance. Focusing on statistical data to monitor and manage compliance to a zero harm workplace creates a significant internal disconnection as sites are assessed by 'hard' data targets. The challenge with 'hard' data reporting is a lack of awareness and assessment of the qualitative data that exists in the practice and process of reporting. The quantification of zero harm although providing an indicator of performance contradicts the simplicity of the Stay Safe message results in the corporate voice promoting an intangible philosophy. Within the WHSEQ function it is a sentiment that in the words of interviewee 2 that zero harm is not so much about *“reporting performance but rather an overarching ideal of a safety culture and its symbolic yet simplistic message”*.

This is particularly evident in the push from the WHSEQ function for sites to utilise the specific reporting platforms, interviewee 8 is a WHSEQ advisor looking after 8 different sites across 3 states; and is the face of the WHSEQ function on sites, when discussing this the interviewee highlighted:

“...corporate leaders within the division do not understand that people at site are busy and do not have the time to comply not only to the notion of a zero harm work environment but to all systems used within the organisation to support a zero harm workplace. Added to this is the time required to ensure ongoing technical support and management of use”. Interviewee 8's point of view reflects the inability of the overarching WHSEQ function to understand the specific cultural, operational and performance needs of each individual site; this view is further supported by all senior and site management interviewees.

This basic disconnection between the organisational WHSEQ function and sites suggests a culture discourse is present; representative of the understanding and awareness of the zero harm safety programme. Understanding the safety culture is central to unlocking the achievability of the programme.

Zero Harm Culture

The safety culture of the organisation is positioned around the achievement of targeted reporting and metric KPI's. Overarching KPI's are set by the corporate team and are representative of individual and with divisional KPI's set by senior management to align to business goals. Despite having a set KPI's, there is limited transparency of monitoring or communication across the site; with reporting only present in monthly reporting and senior leadership meeting. When discussing the matter with site management the lack of transparency is due in part to sensitivity of information sharing, interviewee 7 (a senior project manager) explained:

“...we have more than enough to already report on, let alone provide employees with KPI transparency. If they really wanted to know more then they know where to find all our reporting. Anyway, here employees simply want to come to work and, you know, work...”

The notion of accountability becomes an apparent trend in the above statement; particularly in the interviewee's opinion that employees come to work just to work. Many of the employees within the organisation want to know how the site is performing overall and how they as a team can assist in continually to improve. The

overarching disconnection between site management and employees is quite apparent here and suggests a larger underlining problem not linked to safety but communication lines in general. To have such a pre-existing ideal in place within the organisational environment can promote a safety culture that is simply complying to the Health and Safety Management System because they have not, not because they want too.

This is a concept that has been explored and explained in the DuPont Bradley Curve (DuPont, 1995), which places organisations within a set cultural framework in which to benchmark overall safety performance and compliance. The Bradley Curve explains as an organisation become transparent in its reporting, the culture similarly changes becoming less compliant and more proactive (committing to reporting because they want too). It is interesting to note that there are elements of the DuPont Bradley Curve present; talks with the focus groups discussed the reasoning behind the lack of incident reporting. The problem within the organisation lies with the site incident target of 0 LTIs and 0 MTIs within a financial year. A KPI target that has been in place for the last 5 years and as such no LTI or MTI has been recorded on site; despite the site operating within a high risk work environment. The general consensus amongst the workers was that the reporting of incidents inline to organisational requirements resulted in a culture that fears retribution. Retribution was characterised by employees describing those who reported incidents would be more likely to be targeted by their employers, FG 1 described this as:

“...if you report incidents on site you are more likely to have a target painted on your back...the way you are treated makes you feel like you are in prison...”

The alignment of specifically zero KPI targets contradicts the organisation's overall Stay Safe message which promotes the reporting of all related Health and Safety Management System objectives. The clear disconnection and lack of awareness between the function which sets targets and the application of targets at the site level, is a fundamental issue of practice that is not readily remedied and challenges the ultimate achievability of zero harm.

CONCLUSION

The concept of zero harm ultimately provides an organisation with a goal in which to strive toward which is more of an ideal than a concept. Within Australia the push for the zero harm organisational environment, can be linked to the harmonisation of workplace health and safety legislation, contractual relationships, industry competitiveness and industry compliance. Harmonisation and streamlining performance guidelines and expectations can further provide a framework in which to apply and make zero harm achievable; although the final outcome would be ultimately zero.

The dependence on external factors to set safety performance is cause for concern as it creates a dystopian work environment that does not challenge or change practice, rather seeking workforce engagement without empowerment to address existing problems (Sherratt, 2014). This is representative of an organisation simply being compliant to the needs and desires of the WHSEQ function. Being told how to conform without understanding the larger problems at hand within the organisation and will lead to an operating environment that characteristically will withhold information that is deemed too sensitive or breaks the zero harm boundaries.

Zero harm however can change how we view construction best practice and the larger industry, through the empowerment of the workforce to become more actively

involved in developing best practice. Changing zero harm will ultimately be achieved by establishing more realistic reporting boundaries that reflect a change in focus and provide the supporting framework for the organisation.

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HEALTH AND SAFETY ISSUES AND MITIGATION MEASURES RELATING TO ADAPTIVE-RETROFIT PROJECTS: LITERATURE REVIEW AND RESEARCH IMPLICATIONS FOR THE GHANAIAN CONSTRUCTION INDUSTRY

Frederick Owusu Danso¹, Edward Badu², Divine Kwaku Ahadzie³ and Patrick Manu⁴

¹*Department of Building Technology, Takoradi Polytechnic, Takoradi, Ghana*

²*College of Art and Built Environment, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana*

³*Centre for Settlements Studies, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana*

⁴*Department of Architecture and the Built Environment, University of the West of England, Bristol, UK*

Adaptive-retrofit projects (ARPs) are associated with dire health and safety (H&S) issues which are fragmented and scattered in the existing literature on retrofitting, refurbishment, renovation, rehabilitation, and repair and maintenance work (5R+M). To effectively guide the safe execution of ARPs, these fragmented and scattered issues together with their mitigation measures need to be identified and consolidated into a single unified coherent insight. Therefore this paper, as part of an on-going PhD research on ARPs in Ghana, reviews academic literature to identify and compile a comprehensive list of the H&S issues with their mitigation measures for ARPs. After performing electronic database literature searches and subsequent critical examination of the literature obtained, thirty-six (36) health and safety issues/challenges and twenty-six seven (27) mitigation measures relating to execution of ARPs were identified. These findings provide a sound preliminary basis for further empirical studies towards the development of a coherent and unified guidance for the safe execution of ARPs in Ghana while taking into account local conditions that could also induce additional H&S issues which may not be apparent in the extant literature.

Keywords: adaptive, health and safety, retrofit.

INTRODUCTION

Compared to regular construction work (i.e. new works), ARPs suffer from a relative dearth of literature on occupational H&S. The existing research on ARPs appear to mainly highlight the significance of H&S on ARPs or provide fragments of insights on the H&S challenges relating to ARPs without providing a comprehensive and coherent examination of the key H&S issues and their associated mitigation measures (cf. Langston *et al.*, 2008; Bullen and Love 2011; Xu *et al.* 2012). A thorough identification of these issues together with their related mitigation measures could constitute the basis for the development of a comprehensive and joined-up H&S

¹ ofreddanso@yahoo.com

guidance for the safe execution of ARPs. Therefore, the purpose of this study is to delve deep into the construction H&S literature to draw out a comprehensive list of the key H&S issues and their related mitigation measures for ARPs. To achieve this, this paper starts by highlighting the dangerous nature of ARPs. The paper subsequently delves into the construction H&S literature as well as literature on ARPs to elicit the H&S issues that are often encountered on ARPs and their related mitigation measures. A discussion of the implications of the outcome of the review for further on-going research on ARPs in the Ghanaian construction industry is presented

WHAT IS ARP?

Adaptive-retrofit is a joined-up word from adaptation and retrofitting as applied to existing built assets. Adaptation, according to Douglas (2006), Wilkinson *et al.* (2009) and Ankrah and Ahadzie (2014) is an all-in concept comprising of refurbishment, renovation, rehabilitation, and repair and maintenance work (4R+M) applied to existing built assets to improve their physical form to continue or take on new functions or uses. On the other hand, retrofitting, according to Xu *et al.* (2012) and Dixon (2014) embraces the additions of modern plumbing, heating, ventilation, air conditioning and telecommunication services to existing built assets to improve their mechanical services and energy consumption. Retrofitting also includes the addition of components or features (which were originally not part of an existing building) to the existing building (Douglas 2006). In an attempt to achieve low-carbon emissions from existing built assets and make them more energy-efficient while meeting the modern needs of occupants, society and infrastructure development, the concept of retrofitting is most often than not connected with adaptation (Dixon 2014) though it can be applied separately to existing built assets. Since these two concepts (adaptation and retrofitting) are closely linked together in terms of modern infrastructure development, it is reasonable to adopt a common name to represent their usage, hence the term adaptive-retrofit (AR).

Adaptive-retrofit projects (ARPs) are thus built assets that have been subjected to refurbishment, retrofitting, renovation, rehabilitation, and repair and maintenance work (5R+M) to improve their physical form and energy consumption while continuing to perform their old function or new uses and also satisfy the needs of modern occupants, society and infrastructure development. Literature however signals that each of the 5R+M has their own confronting or peculiar H&S challenges. For example, previous report indicated that refurbishment work alone in the UK construction industry accounted for about 40.6% of the total number of construction fatalities (Anumba *et al.* 2004). Repair and maintenance work have also been reported to be responsible for a high proportion of 43% of the total number of fatal accidents in both building and civil engineering industry in UK (cf. Anumba *et al.* 2006). Hon *et al.* (2010) mentioned that the accident ratio of repair, maintenance, and alteration and additional works in the Hong Kong construction industry compared to new builds have significantly increased from 17.9% in 1998 to 50.1% in 2007. Also, fatal cases from these works in 2010 accounted for 66.7% of the total number of fatal cases in construction in Hong Kong (Hon *et al.* 2014). In a China-based study, Xu *et al.* (2012) through fuzzy theory identified eight key performance indicators (including a H&S indicator) that require consideration when adapting old hotel buildings. In order of importance, the H&S indicator ranked fourth ahead of other indicators such as energy consumption, resources saving, and stakeholders' satisfaction. Judging from the

above, it is thus not surprising that there is the view that the application of 5R+M to existing buildings is likely to further worsen injury and illness statistics.

THE DANGEROUS NATURE OF ARPS

ARPs are generally described as dangerous projects (cf. Quah, 1998; Egbu *et al.* 1998; Egbu 1999; Anumba *et al.*, 2004 and 2006; Douglas, 2006; Doran *et al.* 2009). The safety challenges ARPs present are either absent or minimal in new builds/works. Recent studies on the H&S impact of construction project features (cf. Manu, 2012; 2014) also provide insight of how demolition, refurbishment and new builds potentially influence accident occurrence on construction sites. Manu *et al.* (2014) reported demolition and refurbishment as having a higher potential to cause harm to workers than new builds. In terms of the likelihood of occurrence of harm (i.e. the risk of harm), Manu (2012) also reported that demolition and refurbishment are associated with a higher risk than new builds. Given that H&S control measures are supposed to be commensurate with risks (HSE, 2000; 2007), it is then without doubt that the H&S control measures that are needed for ARPs cannot simply be exactly the same as the controls used on new builds. Rather the controls that are used on ARPs should reflect the kinds of H&S risks/issues that workers are likely to be exposed to and thus ARPs will need some extra layer(s) of H&S defence in the form of measures and guidance to deal with the inherent H&S issues

LITERATURE REVIEW METHOD

The identification of the H&S issues of ARPs began with a detailed search from peer-reviewed journals that report on construction H&S. Zhou *et al.* (2015) researched and presented the top ten (10) journals that frequently report on H&S management and construction engineering issues. The peer-review journals as identified by Zhou *et al.* (2015) include: Safety Science (SS), Journal of Safety Research (JSR), Automation in Construction (AIC), Accident Analysis and Prevention (AAP), Reliability Engineering and System Safety (RESS), Journal of Construction Engineering and Management (JCEM), Engineering Construction and Architectural Management (ECAM), Journal of Management in Engineering (JME), International Journal of Project Management (IJPM) and Construction Management and Economics (CME). These peer-reviewed journals were selected to guide the review of literature for this study.

Electronic database search using keywords (e.g. adaptation, H&S, retrofits, refurbishment), was conducted on these journals. Titles and abstracts of peer-reviewed papers within those journals that could potentially contribute to the understanding of the topic were identified, read and selected. Further, relevant titles from references/bibliographic lists found in those peer-reviewed papers that could also contribute to the understanding of the topic were also selected. Through this, peer-reviewed papers from journals such as Structural Survey (SS1), Facilities (F), Building and Environment (BAE), Energy Policy (EP), Energy and Buildings (EAB), International Journal of Construction Education and Research (IJCER), International Journal of Injury Control and Safety Promotion (IJICSP) were also considered for the literature review. Electronic books on adaptation, retrofitting, renovation, refurbishment, rehabilitation and repair and maintenance work were also searched from Google Books and Directory of Open Access Books (Doab). Health and safety reports from the UK Health and Safety Executive (HSE) website (www.hse.gov.uk) and papers from conference proceedings that have major themes or titles as adaptation, retrofitting together with health and safety were also considered. Quite apart from using the research keywords alone for the search, Boolean connectors such

as AND, OR, AND NOT were also used to connect the research keywords to form search strings such as “adaptation AND health and safety” and “retrofitting AND health and safety”. The reason was based on the idea that if a paper bears strong links to adaptation and retrofitting of existing built assets then it is likely that its H&S issues will be captured in that paper or report or book.

HEALTH AND SAFETY ISSUES ON ARPS AND POSSIBLE MITIGATION MEASURES

Through the systematic search and reading of the obtained literature, several health and safety issues (over 50) and mitigation measures (over 30) relating to ARPs were initially spotted and tabulated. Through subsequent careful scrutiny of these, multiple occurring (i.e. repeating) H&S issues and mitigation measures were excluded resulting in an eventual comprehensive list of thirty six (36) H&S issues and twenty-seven (27) mitigation measures. The detailed results from the review are summarised in appendix 1 below. The H&S issues are represented by HSI while the mitigation measures are also represented by MM. The repeated items of HSI and MM are presented in table 1 below.

From table 1, eleven (11) similar health and safety issues were spotted twice and five (5) similar health and safety issues were also spotted three times from different studies. For example, regarding safety signs (i.e. HIS 1), Anumba *et al.* (2004) and Doran *et al.* (2009) are of the same opinion that lack of warning signs or safety posters could affect the safety, health and the wellbeing of workers on refurbishment projects. The absence of safety signs or the lack of its understanding, according to Tam *et al.* (2003) are likely to cause injuries (fatal and non-fatal) on construction sites in general. On ARPs sites, where hazards are more commonplace than on new build sites, the lack of warning signs or safety posters could therefore further worsen the likelihood of occurrence of injuries.

Table 1: Recurring H&S Issues and Mitigation Measures

Health and safety issues and Mitigation measures	Frequency of occurrence
(HSI 1), (HSI 4), (HSI 5), (HSI 8), (HSI 9), (HSI 11), (HSI 13), (HSI 14), (HSI 16), (HSI 23), (HSI 26).	2
(HSI 15), (HSI 17), (HSI 24), (HSI 30), (HS34)	3
(MM1), (MM6)	2

Lack of/inadequate site supervision (HSI 5) was also noted from two different studies (see Anumba *et al.* (2004) and Doran *et al.* (2009)). Lack of site supervision has been identified by these authors as a major factor that could affect the safety of workers on ARPs. Inadequate supervision of construction operatives is also generally considered to be an inappropriate construction control that could lead to accidents on site (Suraji *et al.* 2001). Regarding the mitigation measures, MM1 (i.e. undertaking structural safety survey) and MM6 (i.e. provision of safety training (related to refurbishment and demolition) to workers) were spotted in two studies. Anumba *et al.* (2004) and Egbu (1999) share the view that specific safety training is needed for workers on refurbishment projects if injuries are to be prevented or minimised. Hallowell and Gambatese (2009) reinforced this view by mentioning that project-specific training is among the key/essential elements for reducing or preventing construction accidents on site.

IMPLICATIONS FOR FURTHER RESEARCH FOR THE GHANAIAN CONSTRUCTION SECTOR

As confirmed by the review, the extant H&S literature on ARPs mainly either appear to caution and highlight the significance of H&S on ARPs or provide fragments of the H&S issues encountered on ARPs and their mitigation. Given the significance of H&S to ARPs, it is thus important to systematically elicit and consolidate from the extant literature the various bits of reported H&S issues and mitigation. Through a thorough review, a comprehensive list of thirty-six (36) H&S issues together with twenty seven (27) mitigation measures has been developed.

Presently, in the Ghanaian construction sector, ARPs are increasingly becoming common and this can be linked to the need to meet the huge housing and infrastructure deficits within the country (Ofori 1995; Ahadzie *et al.*, 2004; Bank of Ghana, 2007). This situation may not be dissimilar to other developing countries where a similar scale of housing and infrastructure deficits are to be addressed. Whilst the comprehensive lists that have been developed from this study could constitute valuable insight for ARPs execution, they have mainly been based on studies conducted in developed contexts. Therefore the list may still not be fully comprehensive or entirely responsive to some of the local context-specific conditions in developing contexts like Ghana. For instance Kheni *et al.* (2010) mentioned in their H&S study on Ghana that the construction industry is highly labour intensive with a majority of its site workers being illiterates with low skills. They also mentioned the use of poor traditional working methods on construction projects in the industry. Such local context-specific conditions/situations could either induce additional H&S issues or trigger the need for additional mitigation measures for ARPs that are not apparent in the extant literature. It is thus important that for the local Ghanaian context further research work is undertaken to elicit other H&S issues that are not apparent in the extant literature and also to devise commensurate adequate mitigation measures towards the development of a more holistic H&S management guidance for ARPs in Ghana. The further research work is expected to be addressed by three main steps of the on-going PhD study alluded to above:

- 1-development of a conceptual H&S management framework for ARPs in Ghana;
- 2-refinement of the framework; and
- 3-evaluation of the usefulness of the framework. These steps are elaborated below.

The initial step is to develop a conceptual framework which coherently matches the list of H&S issues with their corresponding mitigation measures and then maps them onto the phase(s) of project life cycle at which the measures should be implemented together with an indication of the relevant project participant(s). To enable subsequent refinement of the framework (i.e. step 2) to take into account any context-specific issues for the Ghanaian construction industry, it is proposed that a Delphi method is applied. The Delphi method is an iterative process used to collect and distil the judgments of experts using a series of questionnaires interspersed with feedback (Skulmoski *et al.*, 2007). The method can also be used when there is incomplete knowledge about a problem that does not lend itself to precise analytical techniques but rather could benefit from the subjective judgments of individuals who have a wealth of expertise/knowledge about the problem area (Adler and Ziglio, 1996; Delbeq *et al.*, 1975). Whilst ARPs are becoming common in Ghana, they are still relatively less common than new works. As a result fewer construction professionals in Ghana are expected to have the expertise or knowledge about their execution and hence the inherent H&S issues. ARP execution in Ghana is thus expected to be

characterized by relatively limited knowledge and expertise amongst professionals. In view of this, it is prudent to use a Delphi method as this method enables the use of the collective judgment of a group of experts in investigating such phenomena or problems (that are characterized by limited insight) and coming up with workable solutions (see Adler and Ziglio, 1996; Delbeq *et al.*, 1975). The application of Delphi method in construction management research and more specifically H&S studies is not uncommon as can be seen in several studies (e.g. Chan *et al.* 2001; Yeung *et al.*, 2007; Hallowell, 2009; Hallowell and Gambatese, 2010). This also reinforces the suitability of the Delphi method for this research. In applying the Delphi method, a team of construction professionals who have expertise regarding execution of ARPs in Ghana will be assembled to participate in two or more rounds of Delphi surveys, the aim being to employ their collective expert judgment to refine the framework into a practical guidance for the management of H&S of workers on ARPs in Ghana. The experts will ascertain the relevance of the H&S issues and the mitigation measures (listed in appendix 1) to the Ghanaian context. More importantly, they relying on their local expertise and experiences of ARPs and the Ghanaian construction industry in general, they will also contribute to the research process by identifying other H&S issues (together with their mitigation measures) that are more context-specific and as such may not be covered by the H&S issues and measures in appendix 1. It is envisaged that through this process of inquiry a practical ARP H&S guidance will be developed to address the H&S challenges accompanying the growing ARP sub-sector in the Ghanaian construction industry. For the final step (i.e. step 3) the practical utility of the developed ARP H&S guidance will be evaluated from practitioners' perspectives

CONCLUSIONS

Due to several drivers including sustainability and the need to meet housing and infrastructure demands, ARPs are increasingly becoming common. ARPs are however more dangerous and carry risks that are significantly different from those on new works/builds. As such it is evidently clear that the H&S control measures that are needed for ARPs cannot simply be exactly the same as those used on ARPs. Whilst there is a body of literature on the H&S issues associated with ARPs and their mitigation measures, these have been reported in fragments and as such scattered across the literature on ARPs and construction H&S. As such there is not a comprehensive and consolidated understanding of the H&S issues and mitigation measures relating to ARPs. Through a systematic review of the existing literature a comprehensive list of the H&S issues and mitigation measures is drawn. In order for this generic list to be of practical use to the Ghanaian construction sector, further empirical work is needed to ascertain their relevance and more importantly to elicit other context-specific issues regarding ARPs that are not featured. Three main steps have been proposed to advance this: (1) to develop a conceptual framework which coherently matches the list of H&S issues with their corresponding mitigation measures and then maps them onto the phase(s) of project life cycle at which the measures should be implemented together with an indication of the relevant project participant(s); (2) apply a Delphi method to refine the conceptual framework into a H&S management guidance for ARPs in Ghana; and (3) evaluate the practical utility of the guidance from practitioners' perspective. Through this 3 step process, it is expected that the fragmented and scattered H&S issues of ARPs will be consolidated into a single unified coherent framework to reflect the project life cycle of ARPs.

Furthermore, the gap of the relative dearth of literature on H&S management on ARPs especially in the context of developing countries like Ghana will be bridged

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Appendix 1: Health and Safety Issues on ARPS and Possible Mitigation Measures

Health and Safety Issues (HSI)

- (HSI 1) Lack of safety warning signs or safety posters
- (HSI 2) Inappropriate use of tools
- (HSI 3) Lack of demolition sequences and procedures
- (HSI 4) Absence of temporary structures to support unstable elements
- (HSI 5) Lack of or poor site supervision during demolition activities
- (HSI 6) lack of demolition method statements
- (HSI 7) Lack of site investigation
- (HSI 8) Presence of asbestos materials
- (HSI 9) Presence of deteriorating materials and structural elements.
- (HSI 10) Presence of dropping or falling objects
- (HSI 11) Presence of moving transport vehicles (with excessive speed).
- (HSI 12) Presence of irregular surfaces
- (HSI 13) Presence of spilled or leaked liquids or
- (HSI 14) Presence of debris/ working in an untidy site
- (HSI 15) Presence of uncovered openings
- (HSI 16) Presence or use of unidentified faulty equipment
- (HSI 17) Presence of loose and bare/live electric cable(s)
- (HSI 18) Presence of pollutants such as noise, smoke, and hazardous chemicals
- (HSI 19) Improper handling of materials
- (HSI 20) Presence of operating machine(s)
- (HSI 21) Working with hot processes such as welding, flame cutting, laying asphalt
- (HSI 22) Presence of protruding sharp objects
- (HSI 23) High presence of dust particles from breaking, cutting grinding or drilling cementitious and other particulate materials.
- (HSI 24) Presence of lead-based materials e.g. paints
- (HSI 25) Materials containing asphalt, silica, mineral wool and formaldehyde found during the process of adaptation
- (HSI 26) Working in (hot and cold) confined environments
- (HSI 27) Lack of space around machinery
- (HSI 28) Unknown accumulated gases
- (HSI 29) Presence of pest infested component or elements
- (HSI 30) Presence or use of unprotected or unsecured scaffolding or unlit scaffolding
- (HSI 31) Using inappropriate personal protective equipment
- (HSI 32) Working on weak and slippery roofs
- (HSI 33) Working with unsecured ladder
- (HSI 34) The inherent structural risk (e.g. insufficient structural data, uncertainty of key structural elements, and uncertain structural condition of old buildings)
- (HSI 35) Uncertain conditions of old equipment
- (HSI 36) Working with reckless scheduling

HSI Sources: Sanvidoet et al. (1991), Egbu (1999), Anumba et al. (2004), Anumba et al. (2006), (Douglas 2006), Hein and Houck (2008), Lind et al. (2008), Langston et al (2008), Doran et al. (2009), Bullen and Love (2010; 2011b; 2011a), Othman (2012), Isnin et al. (2012), Zhao et al. (2013)

Mitigation Measures (MM)

- (MM 1) Insisting and ensuring the use of qualified and competent structural engineer to undertake structural safety survey before demolition exercise
- (MM 2) Providing accurate and detailed safety information for all workers on refurbishment projects
- (MM 3) Ensuring that all tools and equipment for the refurbishment exercises have been assessed for that specific task
- (MM 4) Preparing and maintaining an oriented H&S procedure for a particular task
- (MM 5) Ensuring that workers are assessed based on their ability to understand work procedures and safety measures
- (MM 6) Providing a specific safety training for workers assigned to undertake demolition aspect of the refurbishment project
- (MM 7) Organising safety working procedures workshop at all levels and stages of a refurbishment process
- (MM 8) Ensuring that adequate evacuation plans, procedures and means of escape have been clearly defined during construction phase
- (MM 9) Providing a firm control and close supervision especially in hot working areas and activities involving flammable processes
- (MM 10) Providing appropriate portable fire extinguishers in hot working areas and activities involving flammable processes
- (MM 11) Ensuring a proper circulation of air around flammable materials and low-pressure gas cylinders and adequately securing them
- (MM 12) Organising hazardous operation timely and separately to avoid disruption and nuisance with other construction operation
- (MM 13) Ensuring the use of rated electrical equipment and earthing all of them
- (MM 14) Providing red–white striped bands with warning stickers around scaffold poles when using it
- (MM 15) Providing and insisting the use of personal protective equipment (PPE) by all workers especially those undertaking hazardous activities
- (MM 16) Providing and ensuring the use of crawl boards to protect roof-workers, especially those working on fragile coverings
- (MM 17) Arranging and undertaking brief and regular updates on safety precaution and emergency procedures to all parties in adaptation processes
- (MM 18) Adopting a well-understood and recognised warning and safety signs
- (MM 19) Ensuring debris is cleared from adaptation sites.
- MM 20) Construction quality checks during adaptive-retrofitting of old buildings to ensure the safety of workers, materials and plants on sites
- (MM 21) Providing and ensuring effective safety training in recognition of electrical hazards and its avoidance in workplace
- (MM 22) Insisting on the use of non-conductive personal protective equipment (PPE)
- (MM 23) Conducting a detail survey to identify potential electrical hazards and its mitigation measures before work begins
- (MM 24) Insulating or de-energising all power lines before work begins
- (MM 25) Ensuring that safety procedures for all works are followed
- (MM 26) Maintaining regular safety site meetings
- (MM 27) Adopting the system using warning signs for communicating electrical safety

MM Sources: Egbu (1999), Anumba et al. (2004), Douglas (2006), Langston et al (2008), Zhao et al. (2013)

EVALUATING THE EFFECTIVENESS OF FALL PREVENTION PLAN: DO WE NEED ANOTHER SAFETY DOCUMENT?

Yang Miang Goh¹ and Wei Min Goh

Department of Building, School of Design and Environment, National University of Singapore, Singapore

Fall from height (FFH) is a major problem in the construction industry in many countries including Australia, Singapore, Taiwan, and the U.S. In response to the perennial problem of FFH fatalities, the Singapore Manpower Ministry enacted the Work at Heights (WAH) Regulations in 2013. The WAH Regulations requires construction worksites to develop and implement a fall prevention plan (FPP) to eliminate and mitigate risk of fall hazards. Even though the FPP is meant to be site-specific, the FPP is essentially a document that may not have an impact on the risk of WAH. To evaluate the effectiveness of FPP in reducing the risk of FFH accidents, a mixed method study involving a case study, 6 interviews, questionnaire survey and content analysis of 17 existing FPP was conducted. A total of 93 complete questionnaire survey responses were gathered. The analyses suggest that FPP was perceived as an effective intervention in reducing FFH accidents because FPP requires clear allocation of responsibilities, increases the awareness of fall hazards and highlights important fall control measures to be implemented on-site. Nonetheless, the effectiveness of the FPP is limited by issues such as failure to implement the FPP, lack of contextualization to site situations, lack of competency of frontline supervisors and workers, inadequate cooperation from sub-contractors and insufficient management commitment. The study showed that the benefits of FPP are not due to the document per se and many of the FPP documentation are already required in risk management and safety and health management systems. Thus, it is recommended that the FPP documentation be reduced significantly, while retaining key components including site-specific responsibilities, detailed risk assessment and inspection and monitoring. The study provides useful insights on the underlying issues influencing safety and health interventions which are relevant to other countries.

Keywords: fall prevention plan, intervention, risk control, safety management.

INTRODUCTION

Falls from height (FFH) often result in severe injuries, significant cost and lost work time (Hinze *et al.* 2006; Lipscomb *et al.* 2004; Safe Work Australia 2014). The study by Chi *et al.* (2005) showed that FFH is the leading direct cause of fatalities in the Taiwanese construction industry. The 2012 U.S. Census of Fatal Occupation Injuries (CFOI) also ranked FFH top three in fatality numbers (United States Department of Labor 2013). Based on the Singapore Workplace Safety and Health Report 2014 (Workplace Safety and Health Institute 2015), 45% of workplace fatalities came from the construction sector and 30% of the construction fatalities were due to FFH.

¹ bdggym@nus.edu.sg

In response to the risk posed by FFH, the Singapore Workplace Safety and Health (Work at Heights) Regulations 2013 (WAH Regulation) was enacted in 2013. Under the WAH Regulations, a fall prevention plan (FPP) is required for all construction worksites. According to the Code of Practice for Working Safely at Heights (Workplace Safety and Health Council 2013), a FPP is “*a documented site-specific plan prepared for the purpose of reducing or eliminating risk of falls*”. A FPP includes the following 10 components: (a) Policy for fall prevention; (b) Responsibilities; (c) Risk management; (d) Risk control measures; (e) Safe Work Procedures; (f) Use of personal protection equipment; (g) Inspection and maintenance; (h) Training; (i) Incident investigations; and (j) Emergency response.

Since compliance to documented safety rules and regulations is known to be problematic (Hale and Borys, 2013), the effectiveness of FPP in reducing FFH accidents is debatable. Besides the FPP, construction companies in many countries (e.g. Singapore and the U.K.) are also required to conduct and document risk assessment, maintain safety meeting records and training records. Larger sites are also expected to have formal safety and health management systems (SHMS), which usually requires extensive documentation for audit and record purposes. Moreover, the FPP seems to replicate many of the SHMS elements. Thus, this study aims to explore the perceived effectiveness of FPP in reducing FFH accidents. The study provides insight into the factors influencing the perceived effectiveness of a document-based intervention. A mixed method research approach involving case study, semi-structured interviews, questionnaire survey and content analysis was adopted. The data reported herein was collected between 2013 and 2014, i.e. during the initial introduction of the WAH Regulations.

CASE STUDY

An institution construction project (Project A) was selected for the case study, which was meant to give the authors a richer understanding of how FPP was developed and implemented on-site. The case study was kept unstructured to allow the researchers to explore the content of the FPP and site implementation issues. A site walk was conducted with the permission from the management and an interview was conducted with the Workplace Safety and Health Officer (WSHO) of the project. Project A involves the building of a single block of 17 storeys with a basement. At the time of the visit, the site had a total of 450 workers working on-site. Of the 450 workers, about 200 of them were involved in work-at-height (WAH). Out of which 150 were involved in structural reinforced concrete work and the remaining 50 workers were involved in curtain wall installation and brick work.

The contractor developed the FPP at two levels: corporate level and site level. The contractor had chosen this approach because the FPP was meant to be a site-specific document. Thus, the site level FPP had to account for the atypical nature of the projects and the different types of work conducted by the sub-contractors in different projects.

According to the contractor, they were able to use existing resources to develop the FPP. The contractor highlighted that the content in the Code of Practice for Working Safely at Heights (2013) was very useful for developing the FPP. In terms of implementation, the contractors opined that there was no specific improvement because they had been practising the content of the FPP prior to the enactment of the WAH Regulation. According to the contractor, the only difference that the FPP made was the legal obligation for the management to officially endorse the FPP.

SEMI-STRUCTURED INTERVIEWS

After the case study was conducted, the researchers reflected on the findings and planned for six semi-structured interviews. In addition to the semi-structured interviews, site walks were conducted at two of the sites. The interviewees included the workplace safety and health officers or project coordinators. As 2 of the interviewees did not agree to be audio recorded, four sets of interviews were transcribed. The interviews were guided by a list of questions, but the interviewer deviates from the questions in response to the information provided by the interviewees while keeping the purpose of the study in mind.

Based on the interviews, the development and implementation of site level FPP involved several parties such as the project manager, safety personnel, contractor engineers, the consultants and the sub-contractors. Prior to the development of the site level FPP, safety personnel discussed WAH issues with engineers, sub-contractors and site coordination meetings and site surveys were carried out. The discussions were focused on considerations such as identifying activities that require working at height, the work methods to be adopted, and the cost and time required for the WAH activity. After the details of the WAH activities were confirmed, the administrative part of the FPP had to be developed. Some of the key administrative details include records of workers who went through WAH training courses, the personal protective equipment received, and the permit-to-work application for WAH activities.

One of the key challenges was to train personnel for WAH activities because training courses were not easily available initially. Some companies conducted their in-house training to get their site personnel competent in WAH activities. Briefings were also conducted to familiarise workers with FFH hazards and the fall prevention measures stipulated in the FPP. In terms of provision of fall protection devices, much effort was spent on guardrails for open edges, proper access and egress, lifelines, anchorage points and personal protective equipment (PPE) to workers. The direct cost of compliance include the cost of training, purchase of fall protection equipment such as safety harnesses and appointment of WAH assessors to assess permit-to-work for WAH.

One of the key benefits of the FPP was that there were clear responsibilities assigned to management, competent persons and supervisors. The clear allocation of responsibilities increased safety awareness and promoted a sense of ownership (Hung *et al.* 2011). Even though one of the interviewees was positive about the effectiveness of the FPP, another interviewee commented that the effectiveness can only be observed over time. This was because many contractors were still getting their workers trained. On the other hand, it was highlighted that the FPP is only as good as the level of implementation. There were also concerns that the FPP can degenerate into a mere “*paper exercise*”. One of the key barriers to its successful implementation was the cooperation from sub-contractors who were usually the ones that carry out the WAH activities.

QUESTIONNAIRE SURVEY

The online questionnaire survey used in this study was disseminated through various organisations and informal groups, which included Singapore Contractors Association Limited (SCAL), Singapore Institute of Safety Officer (SISO), Facebook pages of workplace safety and health groups, and personal contacts of the researchers. The online survey was active for seven weeks.

Responses

At the end of response period, a total of 210 responses were received. Out of the 210 responses, 110 responses were incomplete and had to be discarded. However, there were responses by safety professionals from other industries such as petrochemicals, oil and gas, aviation and part-time workplace safety and health students who have no experience in the construction industry. Therefore, their responses were also discarded and 93 responses (44%) were used for the analysis.

Profile of Respondents

The age of the respondents ranged from 21 to more than 61 years old, with 42% of respondents in the range of 36-45 years old. 77.4% of respondents had more than 5 years of experience in the construction industry. Figure 1 shows that more than 80% of the respondents were workplace safety and health officers (WSHO), health, safety and environment (HSE) managers, or safety supervisor.

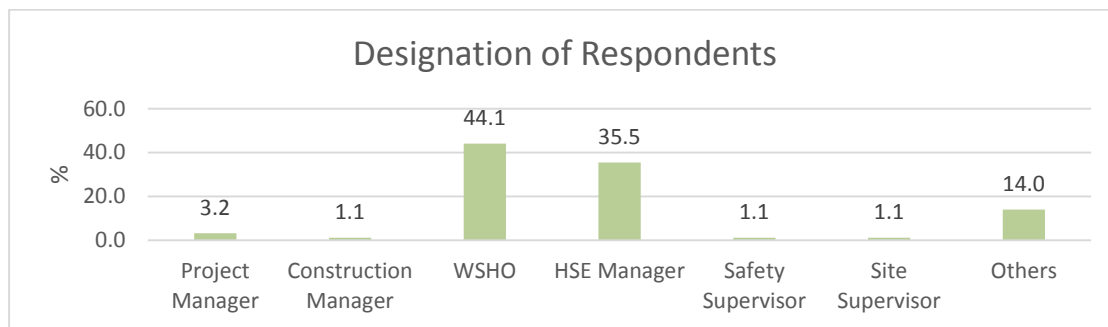


Figure 1: Designation of respondents

Results

With reference to Figure 2, majority of FPPs were developed as an extension of existing risk assessment (RA) and safety health management system (SHMS) (40.9%) or developed from scratch with reference to the CP for working safely at heights with (38.7%). Figure 3 indicates that the development of FPP involved a range of site-personnel.

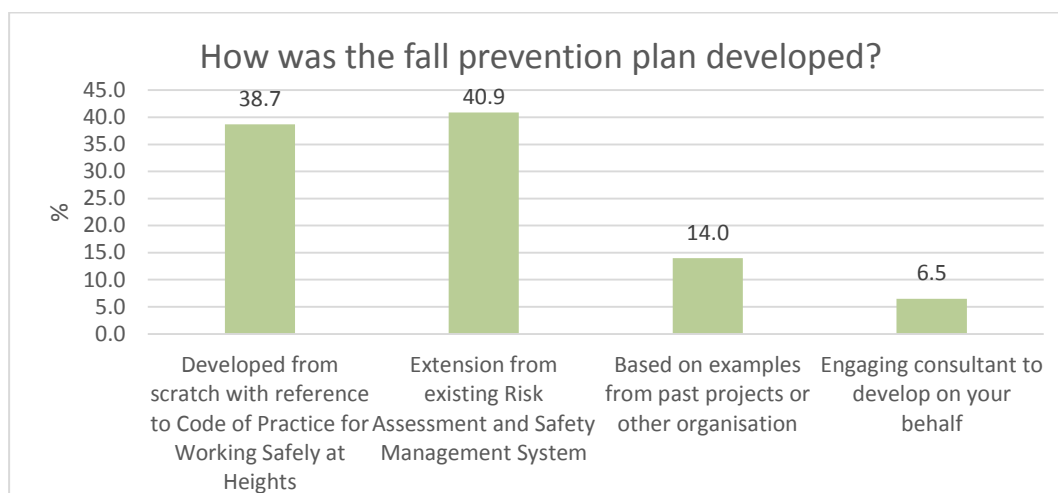


Figure 2: Development of the FPP

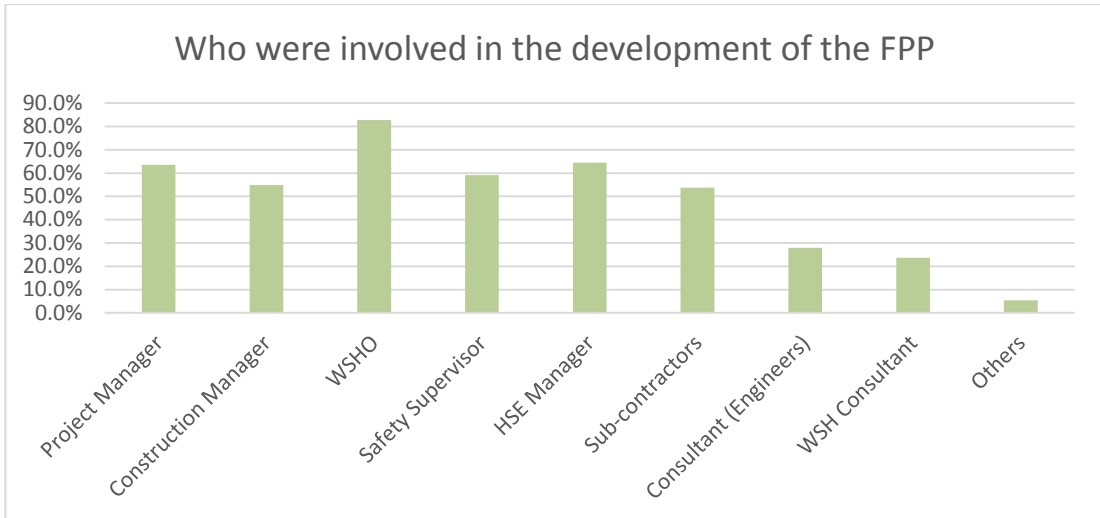


Figure 3: People involved in the development of the FPP

Figure 4 highlights the perceived challenges in implementing FPP. The key challenges include “lack of commitment from sub-contractors” (67.7%) and “not enough competent staff” (64.5%). 47.3% of respondents indicated a “lack of commitment from management” as one of the challenges they face when implementing FPP.

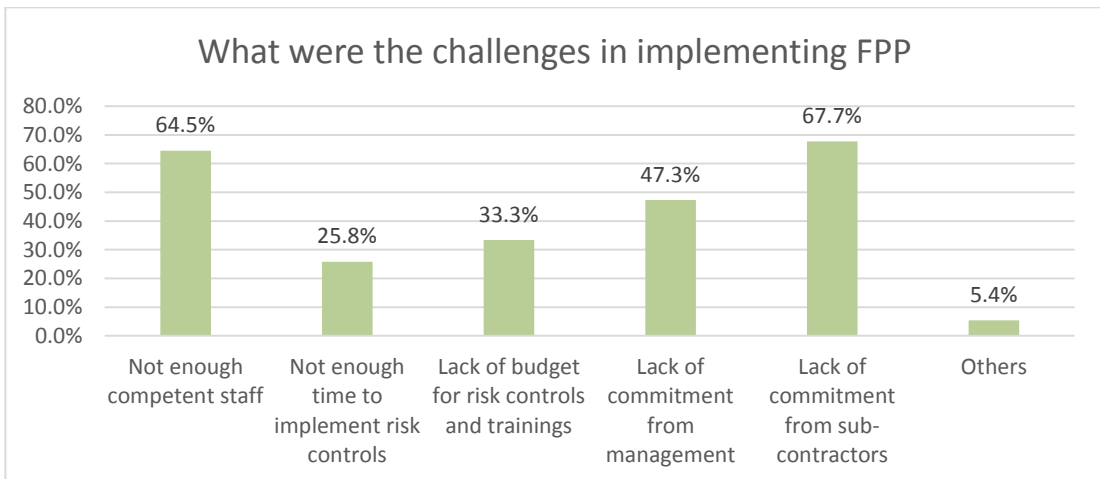


Figure 4: Challenges in implementing FPP

Figure 5 shows that for each of the FPP components at least 59% of the respondents indicated that the FPP component can be replicated from existing safety and health management system (SHMS) elements. It was noted that more than 70% of respondents indicated “Risk management (Hazard identification and Risk Assessment)”, “Safe Work Procedures”, and “Roles and Responsibilities” as components that can be replicated from the existing SHMS elements.

33.3% of respondents (Figure 6) indicated that there was no cost for developing the FPP. 28% indicated “\$2,001 – \$3,000” for developing the FPP. In Figure 7, 53.8% indicated that the cost of implementing FPP is at “1% of contract sum”.

Figure 8 shows that about 80% of respondents thinks that the FPP was effective in improving the safety of WAH.

When asked for the rationale for assigning “effective” or “very effective, respondents provided reasons such as increased “provision for fall control measures”, “increased awareness” and “commitment towards FPP”. On the other hand, the rationale for “no

effect”, “ineffective” or “very ineffective” include “paper exercise”, “lack of commitment from sub-contractors”, “additional documentation” and “unsupportive management”. The respondents were also asked to provide recommendations to improve the effectiveness of FPP. Many of the recommendations were focused on actual implementation on-site, training, and management support.

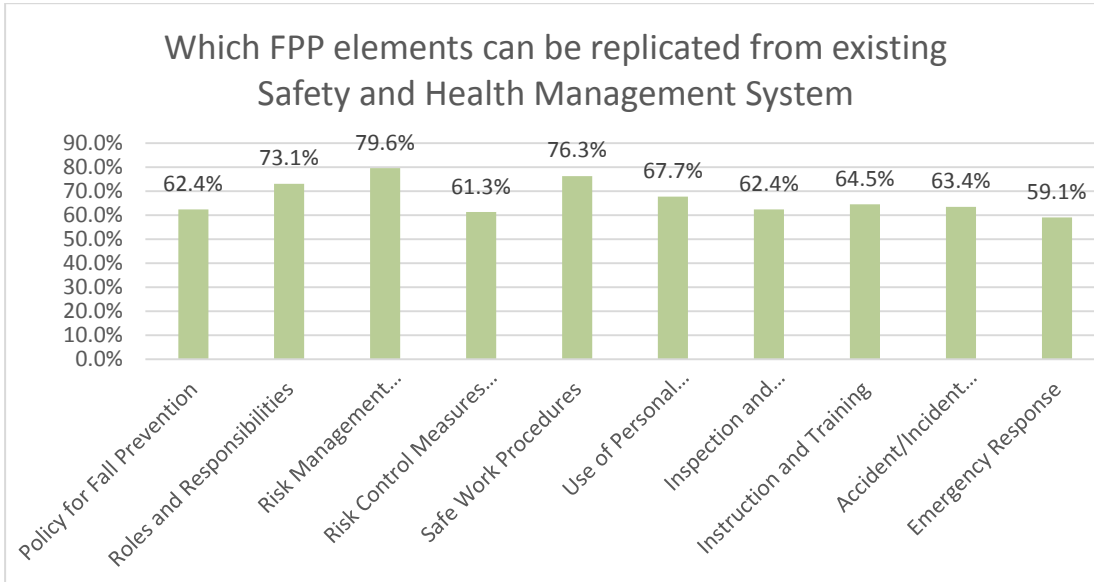


Figure 5: FPP elements that can be replicated from existing SHMS

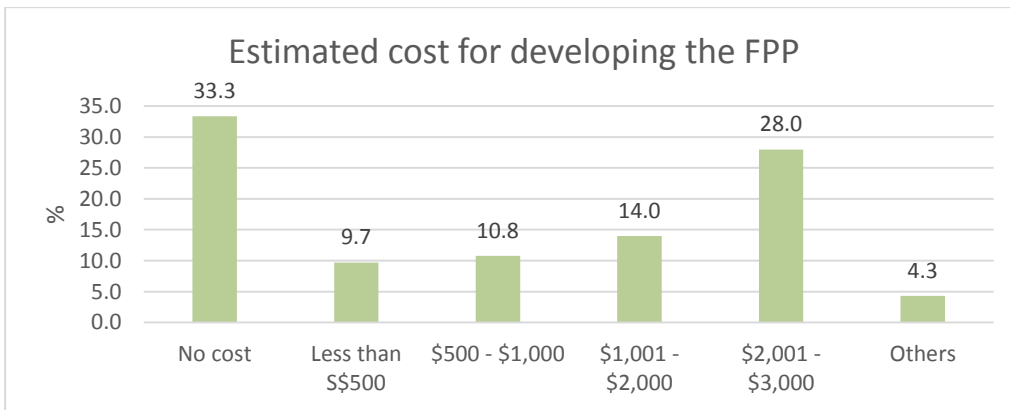


Figure 6: Estimated cost for developing the FPP

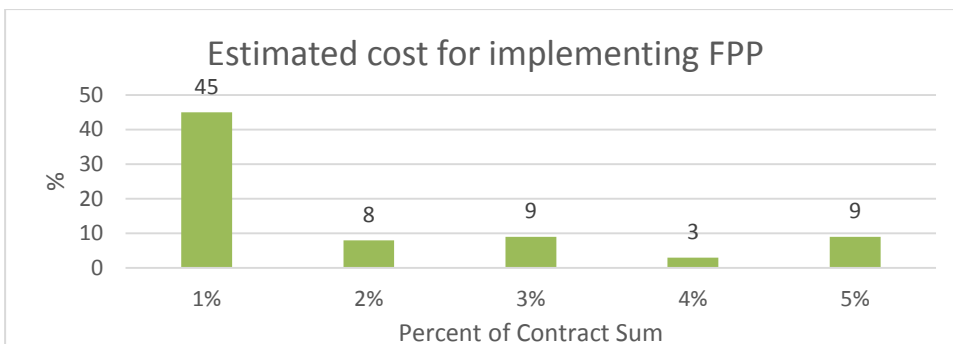


Figure 7: Estimated cost for implementing the FPP

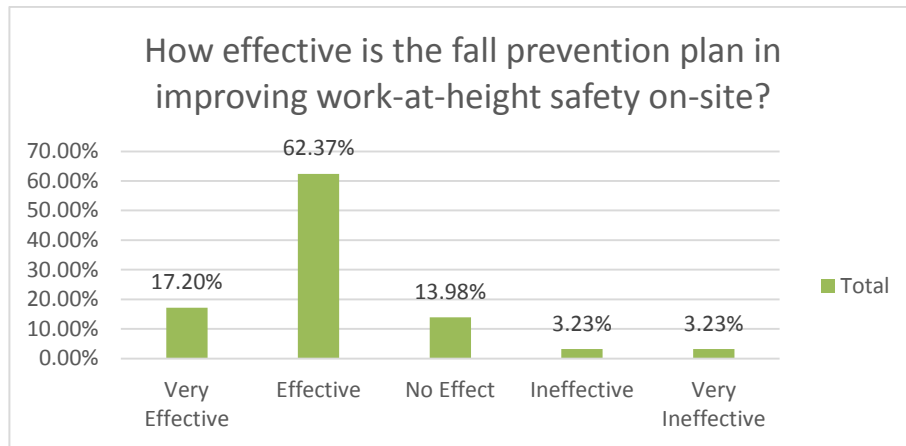


Figure 8: Perceived effectiveness of the FPP in improving WAH safety on-site

CONTENT ANALYSIS

Seventeen FPPs were obtained from the industry during the study. A 33 item checklist was developed based on the Code of Practice for Working Safely and Heights (Workplace Safety and Health Council 2013) and the authors' findings from the case study and interviews. The checklist was categorised into 10 sections. The first 9 sections were based on the 10 components of the FPP, but the components “Risk Management” and “Risk control measures” were combined due to their similarity. Section 10 was included to account for items not explicitly required in the first 9 components, but were deemed to be useful for a FPP. Some examples include reference to relevant regulations and list of sub-contractors' FPP. Each section had 2 to 8 items.

The authors then assessed the 17 FPPs and assigned a “Yes”, “No” or “Unknown” to each of the items. “Unknown” is assigned when relevant attachments or annexes were mentioned in the FPP, but were not provided. The percentage of “Yes” was then calculated for each FPP and for each item. Note that “Unknown” responses were removed from the calculation. For example, for a FPP with 3 “Unknown”, 20 “Yes” and 10 “No” will get 66.7% (20/30). In addition, an item with 2 FPP reported as “Unknown”, 5 “Yes” and 10 “No” will get 33.3% (5/15).

In terms of the score for the 17 FPPs, the average score was 32%, maximum was 71%, and the minimum was 0%. With reference to Table 1, it can be seen that the quality of the FPPs as perceived by the researchers were not high.

Table 1: Percentage of FPP with adequate content for each section

Section	% of FPP with adequate content
Responsibilities	58.8%
Training	54.0%
Policy for Fall Prevention	53.1%
Inspection and maintenance	40.0%
Others	36.0%
Safe Work Procedures	32.7%

Risk management and Risk Control	30.6%
Use of personal protection equipment	17.9%
Incident investigations	16.4%
Emergency response	12.7%
Average	35.2%

The evaluation showed that most of the FPPs were simply repeating the information found in the Code of Practice for Working Safely at Heights (Workplace Safety and Health Council 2013). There was a lack of contextualisation to the site conditions and activities. Many of the FPPs were focused on providing a generic framework and did not provide specific guidance on fall prevention measures.

KEY FINDINGS

Based on the results of the case study, interviews, questionnaire survey and content analysis, the key findings are summarised below.

1. The FPP was perceived to be effective in improving WAH safety because it increased awareness of FFH risk and provision for risk controls for WAH. This could be related to the clearer allocation of responsibilities for WAH safety and increased coordination and discussion on WAH issues. In addition, the additional requirement for WAH training increased the competency to manage FFH risk.
2. The FPP was not costly to develop and implement. This was probably because the FPP were developed based on the existing safety and health management system or the Code of Practice for Working Safely at Heights (WSHC 2013). However, this raises the question on the need for the FPP.
3. The evaluation of 17 existing FPP showed that current quality of the FPP (as perceived by the researchers) was very low. Many FPP were simply repeating the information in the Code of Practice for Working Safely at Heights (WSHC 2013) and did not provide adequate site-specific information on fall prevention.
4. The key barriers to an effective FPP were lack of commitment and lack of competency.
5. There were concerns that the FPP can become a “*paper exercise*” where the plan does not get implemented on site.

RECOMMENDATIONS

As the data was collected within a year of the enactment of the WAH Regulations, the impact of the FPP could not be fully assessed in this study. However, this study helps to assess the sentiments on the ground, provide suggestions for improvement and pre-empt possible problems. The study found that the FPP will not be able to reduce FFH accidents directly, but it did increase safety awareness among managers, and contractors. The industry was not adverse to the FPP because it was not costly to develop and implement. However, the level of quality of FPP appeared to be very low. The following two key recommendations are provided to improve the current situation:

1. Simplify FPP. Since all the components of the FPP can be replicated from the existing safety and health management systems (SHMS), the FPP need not be a standalone plan. However, to maintain the improved safety awareness, commitment, competency and communication, it is proposed that the FPP be scaled down significantly while maintaining the key requirements. This means that components such as policy for fall prevention, use of personal protective equipment, inspection and maintenance, training, incident investigation and emergency response should not be replicated from the SHMS. The requirements for training and responsibilities can be maintained without the need for a FPP. The FPP should focus on being a detailed and site-specific risk assessment document. This recommendation is logical because FFH is a high risk hazard, so construction companies are expected to conduct more thorough assessment of the hazard. Site personnel should be expected to study each WAH activity in detail and risk controls should be identified for specific tasks. The project manager, sub-contractors and relevant parties should participate in WAH risk assessment meetings to discuss the fall hazards and commit to the risk controls identified. The meeting notes should be recorded as part of the FPP, which should be a live document.

2. Monitor the implementation of the fall control measures. To prevent the FPP from becoming a “*paper exercise*”, the actions identified in the FPP must be tracked closely by the project manager and safety personnel. Inspections by competent personnel will have to be conducted frequently. In addition, there must be dedicated communication channels for workers and frontline staff to feedback on the effectiveness of the implemented measures.

LIMITATIONS

There were several limitations in the study. Firstly, the study was relying heavily on the perception of practitioners and their assessment on the impact of the FPP. This limitation was minimised with the different sources of data, particularly the evaluation of the actual FPPs obtained from the industry. Secondly, the interviewees and questionnaire respondents were predominantly safety personnel. More engineers, contractors and construction personnel should be surveyed. Thirdly, the content analysis was based on the evaluation of the research team, this can be improved if experienced practitioners were involved in the evaluation. Nevertheless, one of the researchers is a registered safety auditor and that helped to reduce the impact of this limitation. Lastly, the data collected were focused on the Singapore construction industry and the results may not be applicable to other countries. The study presents a case of how a document-based intervention was implemented in Singapore. The shortcomings and perceived benefits of the FPP were presented, but the impact of the local culture and structure on the findings could not be clearly established.

CONCLUSIONS

As the adoption of the FPP by the Singapore construction industry was still in the preliminary stage, the actual effectiveness of the FPP could not be clearly established. Based on this study, the FPP was deemed to be effective because it increased safety awareness, commitment, resources, communication and competency in preventing FFH accidents. The clear allocation of responsibilities and requirement for additional training brought more benefit than the FPP document itself. In addition, since it was generally felt that all the components of the FPP could be replicated from the safety and health management system, it appeared that the FPP document was redundant. To continue its benefits while preventing the FPP from becoming a “*paper exercise*”, it is

proposed that the FPP should be scaled down significantly and be positioned as a detailed risk assessment document. The document should be frequently discussed and actions closely tracked. Inspections must be planned to assure implementation and suitability of the risk control measures. Dedicated feedback and communication channels must be present to allow workers and frontline staff to feedback on FFH risks and controls.

The study provided insights on how a document-based intervention was being implemented and the underlying issues influencing the success of the intervention. The findings will be useful for organisations and countries trying to implement similar interventions. A follow-up study is being planned to provide a longitudinal evaluation of the effectiveness of FPP.

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INSTITUTIONAL ENVIRONMENT AND INSTITUTIONAL LOGICS IN CONSTRUCTION SAFETY MANAGEMENT: THE CASE OF CLIMATIC HEAT STRESS ON SITE

Yunyan Andrea Jia¹, Steve Rowlinson², Mengnan Xu³ and Baizhan Li⁴

¹ *Department of Construction Management, School of Built Environment, Curtin University, GPO Box U1987, Perth, WA, 6845, Australia*

² *Department of Real Estate and Construction, the University of Hong Kong, Pokfulam, Hong Kong*

^{3 and 4} *Faculty of Urban Construction and Environment Engineering, Chongqing University, China*

Although climatic heat stress can be fully brought under control and prevented from causing short-term or long-term damage to the human body in laboratory experiments, the expected effect of interventions are however often lost in the practice on construction site as frontline personnel are driven by conflicting institutional logics in their specific institutional environment. The paper presents a comparative study between Hong Kong and Mainland China in the case of climatic heat stress management on construction sites. Specifically, we look into how societal culture as institutional logics leads workers and managers to their pragmatic or normative behaviours that deviate from the expected outcome of safety management. Two competing institutional logics in construction safety management are identified and discussed, i.e., production logic and prevention logic. Comparative analysis of the Chinese samples under two different institutional environments identifies two distinct society-level cultural logics that shape personal strategies of reconciling safety and production goals, i.e., Confucianism logic and Chinese pragmatism logic. Their implications on construction safety management are further discussed.

Keywords: construction safety, institutional intervention, institutional environment, institutional logics, production logic, prevention logic.

INTRODUCTION

The behavioural approach has been widely applied in construction safety management to promote safe behaviour among workers (Jiang *et al.*, 2014; Lingard and Rowlinson, 1998). Their effect, however, is not as expected either because the basic management infrastructure is absent or, the institutions do not effectively lead to safe behaviours. The gap between formal institutions and their desired behaviours is rooted in the science-application dichotomy which results in a paradox that OHS guidelines have to be developed through scientific experiment in simplified 'ideal' settings to be valid, yet they are expected to achieve effectiveness in complex workplace situations. In the case of heat illness in summer in construction site, experimentally developed heat stress guidelines have defined environmental thresholds and suggested engineering and work-rest regimens associated with the thresholds. They are however often found dysfunctional or economically unrealistic in the industrial workplace. In a construction site where the thermal environments vary with spatial characteristics and

¹ yunyanbright@gmail.com

change with daily weather conditions and time of the day, numerous risk-mitigation decisions are instantly made by the frontline staff who are busy with production tasks. Our aim of this study is to explore how the institutional interventions, in this case the heat stress management guidelines, are processed on site and why they are not generating the designated effect of mitigating the climatic risk.

Referring to the Loughborough ConAC framework (Haslam *et al.*, 2005), heat stress is an attribute of the workplace located at the immediate circumstance of construction accident causality. Its effective control lies with the shaping factors, such as work scheduling, which is further constrained by the originating influences at upper stream of the supply chain, such as project management or economic climate (Table 1).

Table 1. A summary of the Loughborough ConAC framework (Haslam *et al.*, 2005)

Immediate accident circumstances		Shaping factors	Originating influences	
			Proximal	Distal
1. Workplace	Layout/space; lighting/noise; hot/cold/wet; local hazards	Site constraints; work scheduling; house keeping	Permanent works design; project management; construction processes; health and safety culture; risk management	Client requirements; economic climate; construction education
2. Work team	Actions; behaviour; capabilities; communication	Attitudes/motivations; knowledge/skills; supervision; health/fatigue		
3. Material	Suitability; usability; condition	Design specification; supply/availability		
4. Equipment				

Building on this concept, Rowlinson and Jia (forthcoming) analysed causality of heat illness incidents from an institutional perspective and identified factors at individual, job, team, project, organization, industry, society and ecosystem levels around stakeholder's roles. Institutions are defined as socially constructed laws, structures, rules, regulations, cultures, norms, routines, cognitive frames and established practices that explicitly or implicitly govern individual and organisational decision making behaviours. This definition recognises the regulating effect of implicit principles of behaviours and provides a finer granularity for the study of construction safety in contrast to the rules-compliance approach. The resulted institutional model connects safety risks on construction site to multiple levels of institutions and informs stakeholders at upper stream of the supply chain on possible safety consequences of their decisions, thus leading to opportunities of making effective influence on the improvement of construction site safety.

To understand how institutions influences organisational and individual behaviour, the concept of institutional logics opens the insight into the inquiry of the cognitive base of the constitution of institutions. Institutional logic is "a set of material practices and symbolic constructions" (Friedland and Alford, 1991, p. 248). This definition implies that institutional logics are composed of concrete activities, sensemaking of the activities and communication of the sensemaking. At society level, institutional logics are the central logics of institutional orders of a society, which, subject to further elaboration by organizations and individuals, generate its organising principles. Friedland and Alford suggested five logics of the central institutions in a modern Western society: the logic of capitalism which is accumulation and commodification of human activities; the logic of state which is rationalisation and regulation of human activity through bureaucracy and hierarchy; the logic of democracy which is

participation and institutional control over government (Pettit, 2008); the logic of family which is motivation of human activity by unconditional loyalty to an in-group; and the logic of religion or science which is “*truth and the symbolic construction of reality*” (Friedland and Alford, 1991, p. 248). Institutional logics are historical. Players are bounded by the institutional logics at a particular historical stage; meanwhile they construct and change institutional logics.

In the following sessions we present a comparative study between two systems of one country, Chongqing municipality in Mainland China and Hong Kong, on the effect of heat stress management guidelines as a safety intervention on construction sites. Owing to the same ethnic origin and the special governing structure between Hong Kong and Mainland China, some researcher proposed the Hong Kong system as a model for China’s reform toward a cleaner and more efficient institutional environment (e.g. Manion, 2004). However, an investigation of the institutional logics beneath these two societies by this study will demonstrate that effective improvement cannot be achieved by simplistic imposition of a “*better*” institutional structure or, even a successful experience of another society.]

METHODOLOGY

The study takes a grounded theory approach as an overarching methodology. We developed a compacted daily data collection protocol integrating an array of methods for a 360-degree recording of thermal environment of workplace, work activities and their physiological impact and their organizations. The data were then content analysed, sorted and categorised through memos and constant reflections of the researchers. The HK study was a research project commissioned by the HK Construction Industry Council with an aim of developing a heat stress guidelines for the construction industry. As an outcome of the study the new guidelines has been issued and used in construction contracts by major clients (CIC, 2013). Based on the experience, the study was replicated in Chongqing. Details of the data collection methods have been reported in separate papers (Jia *et al.*, forthcoming; Rowlinson and Jia, 2014).

RESULTS

Both Hong Kong and Chongqing fall into the regions of sub-tropical climate with summer ranges from May to August. The difference is that Hong Kong climate is oceanic while Chongqing climate is inland, which means the summer of Hong Kong is more humid with higher wind speed while the summer of Chongqing has a higher range of air temperature. Data in the HK study were 216 workers (90.7% are Chinese) and 96 managers from 26 construction sites (c.f. Jia *et al.*, forthcoming); in the CQ study were six workers and nine managers from two construction sites. The HK workers sample included 34 trades, while the CQ sample included three trades, including two plasterers, two concreters and two formworkers.

Work routines and incentive structures

Incentive structures in the HK construction sites were differentiated between company-based workers and project-based workers. The former were less paid, had longer working hours but a better job security; whilst the latter had higher workload within a fixed range of working hours and poor job security but were better paid. In the CQ study a clear difference was observed between local and migrant workers. The two plasterers in Site A were local workers, working for 22 to 25 days a month, having the autonomy of choosing their days off. The carpenters and the concreters

were migrant workers in Site B lived in dormitories on site, performing daily work without weekends or public holidays. The carpenters were paid by a lump sum payment for certain volume of work. As a result they often worked voluntarily overtime. The concreters were paid by daily wage. As a result their job was characterised by long working hours, which, in an extreme case, they worked continuously for 48 hours.

Attempt of institutional interventions

In the CQ study, two existing heat stress management guidelines were relevant to the work on construction site. A regional guidelines was issued by Chongqing Municipality in 2007 (Document No. 205, 2007), defining a hot weather day as the forecasted daily maximum temperature above 37°C, and suggesting three levels of administrative interventions based on (35-37°C preparation; 37-40°C controlled work; and $\geq 40^\circ\text{C}$ stop outdoor work). At the national level of China, a heat stress management guidelines was issued in 2012 (Document No. 89, 2012) as an update of a primitive draft guidelines existed since 1960. The national guidelines recognised heat stroke as industry injury and made clear that employers are accountable for a safe working environment and specified a similar threshold system to the CQ guidelines. There are three other national guidelines identical to ISO 7243 and ACGIH TLVs but are not applicable to outdoor construction work.

In Hong Kong, there were two guidelines relevant to climatic heat stress management and applicable to construction work by the time of the research. They were an initial guidelines issued by CIC (2008) and a heat risk assessment checklist published by Labour Department of the HK government (2009). The CIC 2008 guidelines specify responsibilities of stakeholders of construction project, followed by description of consequences of heat illness and recommendations of safety measures. Neither of the two guidelines adopted an environmental threshold system.

Our field study found that neither of the two guidelines was in use. In compliance with the requirement of safety management, most construction sites had a formal risks assessment procedure in place; however, climatic heat stress risk was not among the risks being assessed. As organisational initiatives, two sites were found to be trying to apply certain threshold systems, one applied the American Heat Index chart (Steadman, 1979, 1984) while another used the Canadian Humidex chart (Anderson, 1965; CSAO, 2007, 2010; Masterton and Richardson, 1979). Our field study found that the adopted threshold systems could not give a sensible indication of the local climate of HK thus had little influence on the decision making of frontline staff. Analyses of field studies found that none of the existing guidelines were well known among site based staff. In the CQ sample, 60% workers and 66.7% managers did not know the existence of the guidelines, while in the HK sample 66.7% workers and 49.4% managers are unaware of the existing guidelines. Among those who were informed of the guidelines, the HK samples received the information mainly from formal institutionalized including training, supervisor, or Internet research (as part of manager's work). In CQ, 22.2% managers reported to be informed through formal training while the rest of workers and managers get the information from public media and personal networks.

Effective interventions: formal vs. informal

Effective interventions are identified through triangulation of multiple sources of data. Among the identified effective interventions, the two samples are in common in terms of shade, ventilation, drinking water, first aid and buddy system. Those that the two

samples are not in common are listed in Table 2. A clear pattern can be seen from Table 2 that the Chongqing sample relies more on informal and passive measures, while their Hong Kong counterpart identifies more with formal institutions.

Table 2. Differences in the effective interventions identified in the two studies

	CQ sample	HK sample
Effective interventions in difference	Air conditioned dormitory	Mechanical aids
	Toolbox talk	Training
	Ageratum Liquid (Chinese medicine)	Prohibit alcohol
		Advice workers taking necessary rest
		Remind workers on personal health
		Arrange regular breaks
		Inform supervisor of early symptom

Norms prevail over rules: conformity vs. compliance

A drunken worker on construction site is a safety hazard to both himself and others around, as his alertness, motor coordination and control are impaired by alcohol (Levitt and Samelson, 1993). For this reason, construction sites in both Hong Kong and China have set up formal rules to prohibiting alcohol. In relation to heat stress risk, alcohol dehydrates the body therefore increases one’s vulnerability to heat illness. For this reason, the prohibition of alcohol was specified in the Hong Kong 2008 guidelines for heat stress management. The site observation and interview data of this study found this formal institution was in most cases not practiced, indicating a norm of alcohol drinking prevails over the formal rule.

A worker in the Chongqing site indicated that he drank a bottle of beer during lunch in summer, for “cooling down the body”, and some rice wine during dinner “for health”. It was observed that drinking beer during lunch was a norm among workers. In a similar belief, a female worker in the Hong Kong site mentioned that she needed to drink some rice wine “to give me strength for this heavy work” in spite of an awareness that she would be dehydrated. Similar justification was given by a group of rebar workers for drinking beer when working in hot weather, reflecting a norm among construction workers for recharge of physical strength and a feeling of cooling down through alcohol drinking.

Rather than being seen as a violation of rules, the norm of alcohol drinking was well accepted by the frontline managers. In the Chongqing site where no formal rules of banning alcohol existed, a nondrinker manager rejected the idea of setting such a rule and gave the reason as “People like it. You can’t prohibit people’s hobby.” In the Hong Kong site where alcohol drinking was formally prohibited, a manager described the reality on site as, “The rebar trade is used to drinking alcohol, because it is their norm”.

To go even further beyond, the norm in some cases prevailed over the formal rules to ‘cause’ workers’ alcohol drinking behaviour. For example, in the Hong Kong site a plasterer working for a subcontractor openly stated that he drank alcohol over lunch. The reason he gave was “I have to drink with my boss, or he wouldn’t hire me for the next job!” In this case, the norm was internalised into a social obligation.

Historical dimensions of market logic

Market is a societal institutional logic field that brings in values of individualism, willingness to work for gain, trading leisure for income at the margin, and victim-blaming (DiMaggio, 1994). These are jointly formed by the legislative, spatial and temporal structures of the specific societies. Two different market logics were explicated in the patterns of fatigue and the attitudes toward acclimatisation in this study.

Two major dimensions of fatigue leading to heat illness are identified, which are sleepiness and lack of energy. Lack of energy is associated daily cardiac cycle, e.g. in the situations of long continuous work, working with an empty stomach before lunch or working immediately after lunch. Sleepiness is associated with quantity and quality of sleep. Quantity of sleep is influenced by external factors such as working hours and travelling time. The quality of sleep is influenced by workers' personal health and work-life balance. Off-work abuse of alcohol or drug influences both sleep quality and quantity. Both Hong Kong and Chongqing samples agree on the importance of continuous working time (CWT), or, lack of break, as a prominent heat risk factor. In Hong Kong, the Noise Control Ordinance (Cap 400) specifies that no construction work is allowed between 7 p.m. – 7 a.m., which leads to a compacted workload within the restricted 12 hours of the day. There was no such an equivalent legislation constraining construction working hours in Chongqing, where tasks were subcontracted and packaged to teams; works were mostly self-paced. The onsite accommodation enabled workers to do their work very early or very late in a day and stay in air-conditioned dormitory during the hottest hours of the day.

Apart from the influence of external institutional environment, continuous work time and quantity of sleep are also determined by workers' personal priority, which is a reflection of the societal culture. For example, the rebar team collectively determined whether they took a break or not at the beginning of a working day. Often collective decisions were made to cancel the break on Wednesday afternoon for an early off for Hong Kong's weekly horseracing event at night. In the cases of Chongqing, it was observed that although the site was facilitated with a well-equipped canteen, it was almost empty during lunch time. In contrast, the majority of workers rush to a street food court of a very poor hygiene condition outside of the construction site. When workers were asked whether their choices were based on price difference between the canteen and street food, the answer was no. Instead, the key factor that led to such decision was "*time for a nap*". To buy a set lunch in the official canteen, workers need to queue and wait, whilst the private street food court was operated in a much more efficient way. There workers threw their money into a bucket, helped themselves on choices of food, finished lunch and rush back their dormitory for a nap before starting the afternoon work. The risk of fatigue is thus minimized despite of their incredible long working hours. On this, the Chongqing workers set in their personal priority on the avoidance of fatigue, a contrast to the priorities of their Hong Kong counterparts.

Lack of acclimatization was recognized as a prominent risk in the Hong Kong sample but not in their Chongqing counterpart. A worker in the Chongqing site explained why he believed an acclimatisation protocol for newcomers was not necessary, "*It is one's own responsibility to make sure he has enough capacity to do the work he chooses to do. If he wants the high wage he has to work fast. If he cannot catch up then he has to leave.*" It is clearly a manifestation of a victim-blaming value. In contrast, in the Hong

Kong study both workers and managers agreed that “*newcomers should be given time to work slowly to adapt to heat.*” Although the acclimatization protocol was often not fully practised, it was well accepted as a necessary means for working in heat.

Societal institutional environment and its associated temporal and spatial structures constitute the different market logics in the Hong Kong and the Chongqing studies, indicating the historical dimension of institutional logics. The Chongqing sample was reasoning along a rational market logic which assumes independent and competitive individuals (Daly and Lewis, 2000) willing to work for gain and to sacrifice leisure for income. While the Hong Kong sample sees a more mature individualism that emphasizes individual autonomy and accepts of individual rights and wellbeing (Turner *et al.*, 1986). The contrast in characteristics of components that constitute the two different logics are briefly summarised in Table 3.

Table 3. Prevailing societal logics in the two studies

	CQ study	HK study
Prevailing societal logics	Rational market logic	Individualism
Institutional constraint	None	Noise Control Ordinance
Spatial characteristics	Mixed work and life spaces	Clear separation of work and personal life
Temporal characteristics	Stay in dormitory during hot hours; no leisure time	Continuous work; daily commute time 2-3 hours; more time for off-work activities
Individual priority	Rest	Freedom

Logics of processing safety in production

Distrust between employers and workers has been an obstacle for effective safety management. The latter is embedded in the reward-sanction system of the organization while the former varied in their manifestations through the two different societal cultures. In the Chongqing study, although workers identified toolbox talk as an effective intervention for disseminating heat stress prevention knowledge, they also identified it had never been practiced. Workers made sense of this non-action as “*they’d rather keep us ignorant so that they don’t have to pay for the Chinese medicine required by the guidelines.*” A different mechanism of generating distrust is seen in the Hong Kong study. Rather than complaining about the absence of safety efforts from employers, Hong Kong workers instead felt overwhelmed by the numerous safety programmes on site that cut into their time for production work by which they were paid. Workers made sense of the safety programmes as “*managers are working for their own rice bowl*”, while safety programmes in practice was not trying to achieve improvement in workers’ safety and wellbeing. The comparative analysis defined two different patterns of distrust signify two different institutional logics at the organisational level: a prevention logic and a production logic. The prevention logic in the Chongqing sample was underneath workers’ self-initiation and their personal priority of staying safe in the absence of a safety management infrastructure. In the Hong Kong sample, while the existing management system ensured a certain standard of safety, the extra effort on safety initiatives was processed in more of a symbolic sense, as extra tasks to the production work.

The differences in procession of prevention logics are further explained by the logics of societal culture that determines individual sensemaking. Liu *et al* (2010) describe

that traditional Chinese society is characterized as a high culture of the Confucianism of the gentlemen and a low culture of pragmatism among ordinary people in the field. Central to the Confucianism culture is the value of benevolence (Ren), expressed as “do not do to others what you would not have them do to you” (Analects of Confucius), which is a reversed expression of Matthew 7:12. While Chinese pragmatism is a set of values that is against any consistent values system but to achieve the material goals, often short-term, regardless of the values of the means, based on a belief that “the ends justify the means”. The Confucianism logic was expressed in a manager’s statement in the CQ study: “According to the Three Cardinal Guides, a king should be a role model of his subjects. Applying to our time, it means a cadre should be a role model to the masses; a boss should be a role model to his employees. Bosses should be caring about their workers’ wellbeing and workers will follow their example to work hard to achieve their production goals.”

In contrast, the pragmatic logic was seen in the Hong Kong study in which employers performed safety as a task of satisfying external institutional requirements while workers felt exhausted by these extra tasks they were not paid for. By this, safety is decoupled from its meaning. The constitutions of the two different prevention logics are summarized in Table 4.

Table 4. Procession of prevention logics in two different institutional contexts

	Chongqing	Hong Kong
Dominant societal culture	Confucianism	Pragmatism
What is prevention	Free from work	Another production task
What is production	In spite of safety risks	Core business
Incentive structure of prevention logic	Self-initiatives (informed by public media)	Organisational initiatives in response to external institutions and market
Structures to enable prevention logic	Onsite accommodation; flexibility of working time	PPE free area, inspection, morning brief, site nurse, posters, reminders
Safety is whose interest	Workers	Employers
Interest of the counterpart	Profit	Individual freedom
Accountable to	Personal wellbeing	External institutions
Central question	Prevention or production?	Which to prioritize?
Core issue	Contradict safety and production	Decouple safety from its meaning
How to reconcile	Benevolent leadership	Authentic leadership

DISCUSSIONS AND CONCLUSIONS

The concepts of institutions and institutional logics help explain why certain institutional interventions generate safe behaviors in one context but not another, or for certain period of time but not effective for long. They also help predict the change of institutions and their consequential organizational and individual behaviors. While the behavioural approach emphasizes rules and compliance, Elsenbroich and Xenitidou (2012) differentiated compliance from obedience and conformity as motivations of normative behaviors. Our analysis on the alcohol drinking behavior suggests that norms as implicit institutions often have more governing power over

behaviors than the formal institutions do. On the historical dimension of market logics, Yang (1989) identifies three modes of economy in the 1980s in Mainland China: state administered economy, capitalism and an economy of *guanxi*. The first is based on under-informed bureaucracy; the second on market; the third on Confucianism kinship. Our Chongqing study, after three decades of Yang's study, finds that the mode of state administered economy has diminished in the construction sector while capitalism is dominant, which is manifested in the rational market logic embedded in both the organisations' incentive structure and the workers' blame-victim mindset.

Our comparative study suggests that in the practice of construction site, one-size-fits-all institutional interventions are either shelved or, if powerfully imposed, ending up provoking pragmatic reactions, rather than compliance, that lead to unintended outcomes. In an attempt of understanding deviated consequences of business decisions, Goh *et al* (2012) mapped out the production and the prevention dimensions that interact in a way that the organisational system as a whole drifts towards accidents, as theorised by Reason (1997). The institutional logics explicated through this study provide further insights into how individuals and organisations make sense of the ownership of safety and the obligations of mitigating safety risks. New and informal institutions are being constructed through the misinterpretation and distrust between managers and workers, or their collective blindness to certain risks bounded by their cultural contingencies, and internalised to shape behaviours. Further cross-cultural and cross-national studies are needed for validation of the explicated institutional logics in this study.

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DOING THE 'FUNKY CHICKEN' TO COMMUNICATE ON MULTINATIONAL PROJECTS

David Oswald¹, Simon Smith² and Fred Sherratt³

^{1 and 2}University of Edinburgh, King's Buildings, West Mains Road, Edinburgh, EH9 3JN, UK

³Anglia Ruskin University, Bishop Hall Lane, Chelmsford, CM1 1SQ, UK

An influx of migrant workers to the UK in recent times has meant the construction industry has had to adapt to nationally diverse workforces. In previous studies migrant workers have been highlighted as higher risk, and in 2007 the 25% rise in UK construction fatalities was attributed to communication issues and poor working practices. This study used an ethnographic approach to explore challenges created by a nationally diverse workforce on a large civil engineering project (+£500m), with particular focus on communication issues. Communication barriers meant that safety inductions took longer and bilingual workers were distracted from their work to translate. There were times when no translators/interpreters were present, and to overcome communication barriers a 'funky chicken dance' was used; or in other words, communication through noise and many body and hand movements. The funky chicken dance was sometimes successful in communicating to workers but was far from ideal. National diversity also meant that different ways of working was perceived as acceptable, which led to 'holes' in the procedures and tensions between employees. This study found: that confusion and debate surrounding safe working practices led to errors and confrontation; that safety risks were increased due to the challenges associated with communicating health and safety messages; there was significant reliance on interpreters and no simple way to check H&S messages were being communicated through them; the policy of one worker and interpreter to every six was inflexible and far from ideal; that there was greater difficulty in assessing levels of competency and there was a high turnover of foreign workers.

Keywords: communication, ethnography, migrant, safety.

INTRODUCTION

The expansion of the European Union has led to an influx of foreign workers into the UK from the A8 countries (Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia and Slovenia). In the UK, it is estimated that approximately 88,000 (8%) of the manual labour in the construction industry are non-UK workers (CCA, 2009), which has put pressure on the management of health and safety at a time when the UK construction industry was progressing relatively successfully (Bust *et al.*, 2008). Though comprising of 8% of the total workforce, migrant workers account for nearly 17% of total fatalities (CCA, 2009). Owen (2007) attributed a 25% increase in construction fatalities to communication issues and poor work practices following an influx in migrant workers; a claim which according to Tutt *et al.* (2013), needs to be unpacked in terms of research knowledge. This problem is not only found within the UK construction industry, with research suggesting the United States is facing a similar problem (Hare *et al.*, 2013). Multi-national misunderstandings that occur can

¹ D.Oswald@ed.ac.uk

lead to health and safety problems, and therefore a new approach to health and safety management is required (Bust *et al.*, 2008; Tutt *et al.*, 2011). This paper aims to explore the challenges caused by a nationally diverse workforce on a large civil engineering project (+£500m).

MIGRANT WORKERS

The influx of migrant workers has created additional challenges to employers in the UK (Tutt *et al.*, 2011). The injury rate of migrant workers in Australia has been found to be around twice that of local workers (Geraghty, 1979) - a finding consistent with Dong and Platner's (2004) work in the US, and statistical evidence from the UK (CCA, 2009). McKay *et al.* (2006) found that two-thirds of migrant workers received no health and safety training and the other third tended to have a short site induction that was often not understood or communicated effectively. The issue of understanding has been highlighted by Hare *et al.* (2013) following a study by Halverson (2003) in the US that found training did not result in reduced accident rates among non-English speaking workers. At least in the short term, language barriers are the greatest obstacle to the smooth integration of migrant workers (D'netto, 1997). Despite concerns regarding communication within the construction industry, Loosemore and Lee (2002) argue there has been an insufficient examination of intercultural communication problems within an increasingly diverse construction workforce and found significant communication problems with migrant workers. Communications difficulties have obvious implications including worker engagement and health and safety management (Hare *et al.*, 2013). The importance of safety communications has been highlighted by many in safety literature, with researchers including safety communication in their assessments of safety climate (e.g. Mearns *et al.*, 2003; Lin *et al.*, 2008). Hare *et al.* (2009) believe that an essential starting point is to develop methods of effective communication and Bust *et al.* (2008) and Tutt *et al.* (2011) stress that a new approach to health and safety management is required for nationally diverse projects. Trajovski and Loosemore (2006) recommend that safety training is provided in a variety of languages following strong support for this by non-English speaking migrants in their Australian study. However, some concern has been highlighted that this may hinder foreign worker's integration and could discourage learning English (Commission on Integration and Cohension, 2007). The best long-term investment is considered to provide English language courses (Hare *et al.*, 2013), though this approach may not seem appealing as according to McKay *et al.* (2006) most migrant workers in construction are employed in the short term.

RESEARCH APPROACH

To explore the complex context on a nationally diverse construction site, this study adopted a rationalist ontology and interpretivist epistemology. Within this theoretical framework, reason is the primary source of knowledge (Schuh and Barab, 2007) and there is a belief in the ability of human beings to explain and understand their social world (Uddin and Hamiduzzaman, 2009). Based on this paradigm, an appropriate methodological choice was deemed to be ethnography. Ethnography is an established qualitative method that often uses participant observation as a main research tool and is now emerging as part of a repertoire of approaches for understanding the construction industry (Pink *et al.*, 2013).

For almost a three year period, the researcher was a member of the health and safety department on a large construction project. This provided a common interest with his closest informants, which can lead to assistance and engagement by informants in the

study or project (Murchiston, 2010, p. 92). The H&S advisors each had different site areas in the project and the researcher used the advisors as 'gatekeepers' on the project. A gatekeeper can ease the passage of the researcher's entry, make the surroundings and contexts more visible and understandable, and can introduce a range of possible informants (Pole and Morrison, 2003, p. 26). An overt approach was undertaken which necessitated the establishment of rapport with the participants, and helped overcome any reactivity such as the Hawthorne effect (see Oswald *et al.*, 2014). A 'moderate' participant observer approach was adopted. This is where the participant observer has both insider roles in the research setting and other outsider roles. According to DeWalt and DeWalt (1998) this can provide a good balance of essential involvement and necessary detachment to remain objective. The researcher was often perceived by construction workers as a trainee safety advisor who posed little threat likely to be due to his youthful looks, age, small height and that he was often with safety advisors. As a student still attached to a university, the researcher assumed the role of a novice or an apprentice, a role which can be very productive (Murchison, 2010, p. 42).

Data was gathered from attending safety department meetings, conversations with project employees of different roles, going on organised 'walk-arounds' and viewing photos and safety observation reports. Hence the majority of the data was through recalls of discussions or informal interviews with informants. Due to language barriers, discussions with migrant workers were less common and have not been included in this study. The data was input, sorted and organised in computer software programme, nVivo. The inputted data was analysed using a thematic analysis approach, which gives the researcher a 'bird's-eye view' of emerging patterns that could be drawn out (Aronson, 1994).

An iterative-inductive approach was undertaken, which is not unusual in ethnography (O'Reilly, 2009). This led to the research becoming progressively focused over time; a characteristic funnel structure that ethnographic research should have (Hammersley and Atkinson, 2007, p. 160). One of the focuses that emerged was the findings related to migrant workers and communication, which have been highlighted within this paper. The majority of migrant workers were grouped based on nationality, in an attempt to avoid inter-migrant worker communication challenges. For ethical reasons, and to protect the subjects within this study, names within the following passages are false.

ETHNOGRAPHIC FINDINGS

In the summer of 2014, the project was expecting an influx of different foreign workers on the site. The vast majority of operatives already working on the project were from the UK, supplemented by about a dozen operatives from Spain and Portugal, and a handful from Germany and Poland. The project had already had challenges with the Spanish subcontractor, operating with a mixed Spanish and Portuguese workforce (see Author, 2014) and there had been conflict between the German and Polish operatives. Namely, that they would not speak to each other and displayed a 'hatred' for one another through aggressive intent and confrontation. In a H&S department meeting, this issue was highlighted, with one of the items being discussed surrounding the nationalities arriving and '*if they all get along with each other*'. The issue of communication was also discussed in detail with proposed 'multi-language signage', 'wallet cards to be developed with common statements' and 'black bands on hardhats for English speaking translator'. The translators or interpreters

(these terms were used interchangeably on-site and in this paper) were required to translate text or spoken words and were usually foreign workers who spoke English as well as their own native language. Tutt *et al.* (2013b) found a similar conclusion, that the same person was required to translate (written) and interpret (oral), highlighting a lack of appreciation of the different skillsets. As well as translating, the interpreters had their normal roles and responsibilities as employees such as operatives, foreman or site engineers. In the following months, Croatian, Czech, Romanian and US workers arrived on site.

The rest of this section presents various short and stand-alone ethnographic vignettes that are split up by informant's quotations (in italics), which generate greater understanding on a phenomena under study.

'I spend 40% of my time on 3% of the job'

Communication had been highlighted in advance as being a potential problem, but it was a difficult one to resolve. There were challenges with not only direct communications between employees but there was also time spent and resources used with translations. For example, the H&S induction would take much longer, especially if there were three different languages present, and employees that were bi-lingual were also found to being taken away from their own work to be used as interpreters. One of the H&S advisors was being required to translate the briefs to the workers in the morning. He believed he was spending *'40% of my time on 3% of the job'*. During one of these inductions, one of the Spanish workers asked *'do you mean we cannot jump from man basket to man basket?'*. This type of behaviour could be regarded as a gross misconduct on this project on the UK, yet his questioning suggests this was a behaviour that occurred in Spain.

'It would come out complete nonsense'

Issues with direct communication of safety issues, such as asking the workers to use ear defendant plugs were challenging. Such communications can sometimes be overcome with hand signals, though informants believed that they can be seen as being abrupt e.g. stop sign or 'cut throat' symbol. This can make it harder to make safety interventions in a positive manner. One operative said he had used a translator application on his phone, but *'sometimes it would come out complete nonsense'*. This issue become more of a hazard when successful communication was under time pressure. For example, on one occasion there was a suspended load being lowered; the load started swaying and when this occurs operatives grab the tag line to stop it swaying out of control. At the point where the load began to sway, the worker nearby was of Croatian origin and spoke no English. He was being told in English to grab the tag line, but he didn't understand. This incident was marked as a 'near miss'.

'You feel like you are doing the Funky Chicken'

One of the H&S advisors' said *'you feel like you are doing the Funky Chicken'* to try to communicate with the foreign workers. The funky chicken is a popular rhythm and blues dance where dancers flap their arms and kick back their feet in an imitation of a chicken. He was insinuating that in order to explain what he was trying to say he would need to use many body and hand symbols. He explained that on one occasion he noticed a welder was working without a fire extinguisher close by. He asked him: *'where is your extinguisher'*, but the operative did not understand. Therefore he started trying to represent the size of the extinguisher with his hands, pretending to pick it up and make the sound of an extinguisher hosing down a fire. However, this 'funky chicken' dance could not be understood by the operative. The advisor tried asking again, but this time using 'fire extinguisher' rather than 'extinguisher':

H&S Advisor: *Where is your fire extinguisher?*

Operative (loudly): *FIRE?!*

H&S Advisor: *No No No!*

The operative had understood the word 'fire' but not extinguisher, leading to confusion. The H&S advisor then tried his 'funky chicken' dance again and on this occasion the message was understood - the worker then went to get a fire extinguisher before returning to work.

'If you speak to him in English, he will just say qué'

Bust *et al.* (2008) note that one of the remedial strategies adopted by construction companies is to have at least one English speaking interpreter present in each group, a policy that was implemented on this project (one English speaker in every six).

However, there were suggestions that this policy was not being adhered to at all times. One safety observation report explained that there were two English speaking interpreters but the team was divided into three gangs. When non-English speaking workers were isolated this increased the safety risk on the project. For example, an incident occurred when two foreign workers entered an area, signed onto the briefing sheet without understanding it and went into the construction hoist. On the briefing it stated that the hoist was out of order. Neither of the workers were trained to use the hoist and ended up getting accidentally locked inside.

A H&S advisor thought that the one in six policy attracted '*lip service*'. The policy became strained due to teams being split between the site and the office. In some cases, the management, who were mainly office-based were the recognised translators. In this situation, a H&S advisor thought the policy was '*pointless*'. He also added that a steel fixer had refused to wear the black band which identified him as a translator. The worker had explained that this was because his job description is as a steel fixer, not a translator. Though he understands English, the H&S advisor said that '*if you speak to him in English, he will just say que?'* and that '*he would be willing to do be a translator, if he was paid extra money to do so*'. Tutt *et al.* (2013b) raised the question of whether the informal translation of health and safety documentation is asking too much of migrant workers, especially when they may not be paid for it and it has little long-term benefit on their upskilling, moving through the construction sector or other aspirations. This refusal to take on the interpreter role suggests that there were migrant workers of this opinion.

'They are being trained for everything'

The roles of the interpreters were extremely important since all health and safety communications had to go through them. In a H&S meeting this issue was highlighted by one of the advisors: '*we are relying on these guys to communicate important messages and we have little or no idea what they are saying or how much they are saying*'. Since interpreters were often the only bi-lingual member of the team, they would regularly be put through lots of different types of training e.g. first aid. For some positions, such as the safety rep role, operatives are meant to volunteer but interpreters would often be asked. A works manager believed that they have '*too much responsibility*' and they are '*being trained for everything*'. One of the H&S advisors thought that though this may be the case, he was also aware that his opinion may be shaped by the fact he did not want to '*lose his interpreter for training courses*'. Communication from the top-down was a difficult task, even without the additional challenges a multinational workforce brings, and according to a H&S advisor there were '*many rumours and Chinese whispers on the park*'. Communication sent by email would still need to be briefed to the operatives since they have no access to a

computer, and for the foreign workers they would need to be translated and briefed. Some information was not documented on safety bulletins for fear that the media would use it against the project, which would put more emphasis on communication channels in person and on the interpreters.

'Wee bit maire on the eirrse of it'

Ten Romanians had arrived to work on site and on one occasion I was observing a Romanian operative working alongside a Scottish operative. They were carrying out an operation where a steel structure was being lowered onto the back of a trailer. Once the structure had landed on the trailer, it was light enough that they could push it into place, if it was slightly off-centred. The Scottish operative was taking the lead and said in a very broad accent: *'Wee (small) bit maire (more) on the eirrse (arse) of it'* or in other words, move the back of the structure a little bit more in the same direction. The British safety advisor was also watching this operation laughed because he knew there was *'no way'* the Romanian worker would understand. Despite the lack of understanding through verbal communication, many hand signals were used to complete this job. An ethnographic study by Tutt *et al.* (2011) found that migrant workers used their *'own language'* to communicate through a mixture of hand signals and languages.

Of the ten Romanians that came to work in the summer of 2014, two were removed from site very soon after their arrival because, according to the foreman, they weren't up to the required standard. Both the workers returned to site on a few occasions after their dismissal. This was believed as a desperate attempt to get their job back, though this raised concerns with the security department, who were worried about potential thefts. By November there were only two Romanians left, one of whom had an accident with his shoulder, but struggled to communicate what was wrong with him. Workers being sent home or leaving to be closer to home were not uncommon. Gherardi and Nicolini (2002) suggested that stable groups are linked with lower accident rates; hence such a high turnover can contribute to employee unsafety. In a study by Tutt *et al.* (2013) a multinational team including migrant workers maintained a stable group which *'allows the ongoing development of local knowledge and the fine tuning of interpersonal communication between team members'*.

'They didn't know how to turn it on, where to clip on, how to lower it'

Despite having equivalent qualifications there did seem to be differences in the level of competence. According to Biggs and Biggs (2013) as, well as attitudinal and motivational factor, competence appears to have a direct impact on safety. After an investigation into qualification levels, one H&S advisor believed that some workers had a higher qualification than what would be expected in the UK. Another H&S advisor thought the qualification levels of a group of foreign workers in his area were lower, and that it was evident. He gave an example that the workers had completed the MEWP training yet *'they didn't know how to turn it on, where to clip on or how to lower it'* (because the emergency break was on). He also said that a worker was caught jumping from MEWP to MEWP, a gross misconduct, yet the foreman didn't use any disciplinary action because the subcontractor was leaving soon anyway. Speaking with the workers, the H&S advisor was told they didn't want to come back because it is cold and they can wear shorts and trainers back home. There were also eight workers with no English speakers amongst them, breaking the interpreter policy.

'I've not got anything against the foreign lads but something needs to be done'

One morning, one of the H&S advisors received a call from one of the UK workers. It appeared he was aware that his call could have seemed vindictive, as he stated: *'I've*

not got anything against the foreign lads but something needs to be done'. He went onto explain that the Czech workers were driving into an area cars weren't allowed. The workers were coming in to pick up tools and leave but the UK worker thought that *'someone is going to get knocked over'*. He also said that they are using plant, such as cherry pickers, that *'I know they don't have cards for'* i.e. they are not trained to use. He claimed he had tried to speak to them, but couldn't get the message across, so the Czech workers were just getting in the cherry pickers anyway. The H&S advisor went into the area to investigate, and it was revealed that indeed some of the Czech workers were using machines that they weren't trained to use. Even though the work wasn't *'erratic'*, without deemed competence it could be indefensible in court, so the work was stopped. The training required only took four hours, and according to the HR department, they had requested training but never confirmed their attendance.

'The steel fixers have never used steel before'

There were some suggestions that the foreign workers were very inexperienced and had not worked in construction before. A factor, which according to Stranks (1994), can shape attitudes towards safety. A member of the H&S department stated that some of the *'steel fixers had never used steel before'*. Although he believed they can learn, he saw this inexperience as an extra risk. Soon after the Czech workers arrival there was an incident when they were trying to make grout cement. The seemingly inexperienced workers tried to use five bags of grout and no water and *'flashed out'* the grout pump. A site manager believed *'a lack of experience is the biggest problem on this job'*, that *'you have guys out of their depth'* on such a large project and it was *'all across the board'*.

'The biggest problem the project faces'

In October 2014, I joined an arranged walk-around with a H&S advisor, a H&S representative from the client and the works manager in the area. I was in the back of the group walking with the client's representative, Bill. As we walked past an oncoming migrant worker, Bill said: *'Alright mate, how you doing?'*. The migrant worker past without acknowledgement and Bill turned and said to me *'I could have been saying anything'*. Another migrant worker approached and he again tried to engage: *'Alright big man, how's it going?'*. Again the worker past without any form of acknowledgement.

McKay *et al.* (2006) found that some migrant workers had such poor English they could barely understand what was going on, but in site inductions they were smart enough to head nod at appropriate times, and to work out the induction was completed when others started signing the induction sheet. In Pink *et al.*'s (2010) work, they described how *'similar tactics'* were used by migrant workers, who also had understanding difficulties and displayed a fear of asking questions. In this study, since we passed migrant workers in a group, it may not have been as obvious that Bill was speaking to the migrant workers. This, a lack of understanding, and a fear of engagement as in Pink *et al.*'s (2010) study, could possibly have led to the lack of acknowledgement.

Bill believed the national diversity was *'the biggest problem the project faces'*.

Although there was a mixture of different nationalities, with the project being in the UK, it was being built with accordance to UK health and safety standards. Bill thought that as different nationalities had different acceptable working practices, that the standards expected were not being met. He said that this meant that there were *'holes'* in the safety procedures, and if an accident occurred, it could be difficult to defend the prosecution. This issue was also discussed in the H&S department, with regard to rope

access compliance and the various training levels. One of the advisors thought that: *'there are too many nationalities out there that aren't 100% sure what they are required to do'*.

'The photos speak for themselves'

The different ways of working were a real concern, and there had been multiple unsafe behaviours that had been witnessed, with some being caught on camera. On the walk-around, Bill said *'the photos speak for themselves'*, and that *'we have guys hanging out MEWPS, working at height on beams not clipped on or tied to blue rope; and some of these guys are the supervisors... and you are like, hang on, you are the guys giving the briefs in the morning?!'* One of the Croatian workers had been immediately dismissed for one of these acts in what was deemed a 'red card' offence for gross misconduct. Communicating what was acceptable working practice, changing working practices and keeping consistency with this safety message was a real challenge.

'In some places CDM is just three letters on a scrabble board'

H&S advisors can get the opportunity to travel to different projects around the world. They were in agreement that there were different safety cultures throughout the globe, with one advisor stating that in *'some places CDM is just letters on a scrabble board'*. Note that CDM stands for the Construction (Design and Management) regulations, which places legal duties in the UK. While the H&S advisors anticipated that there may have been different working practices with Eastern European workers, they thought their way of working with the US would *'have been quite similar'* due to the *'connections'* between the two countries e.g. English speaking. However, at the beginning there were differences that caused some friction. On one occasion, a H&S advisor had to stop the hot works being carried out by the American workers because, though they had basic PPE on, they did not have any protective overalls on for hot works. One of the operatives claimed that *'they had worked like this for 40 years'* but the H&S advisor was of the opinion that it *'didn't necessarily mean they had been doing it right'*. This stoppage caused a strong reaction from the American works manager who *'went mental'* and was very confrontational. There was *'a couple of months of tension'* whenever the advisor went into the works managers office but they have since found common interests, that has improved their relationship.

'They are hungry, will work all the hours, will do as they are told and are cheap'

Though there were many challenges associated with a nationally diverse workforce, the migrant workers being employed were cheap. A member of the H&S department thought that employing many nationalities on this project had caused an extra risk. He believed when employing foreign workers people just see the *'bottom line'*. In other words, they just see how much it will cost them. His opinion was that *'migrant workers have been employed because they are cheap'* but once they are here we have to spend resources: *'to manage workers we struggle to communicate with, on workers that are inexperienced and on workers are not used to the UK standards and ways of working'*. Speaking with an experienced civil engineer on the project, he said that you can understand it economically as they are *'hungry, will work all the hours, will do as they are told and are cheap'*.

CONCLUSIONS

A multinational workforce made it challenging to communicate health and safety messages on this project. Interpretations of messages, such as safety bulletins, lessons learned and posters used valuable time and resources, which meant it was difficult to

translate all communications into all languages required. There was a significant reliance on the construction workers who were interpreters as any communication to their teams (of maximum six) would have to be translated through them. Despite being a very important communication link it was very difficult to assess what safety messages were being passed on, or how it was being delivered. The one worker/interpreter in every six workers policy was inflexible due to: work locations (site and office), resistance from migrant workers to act as interpreters, interpreters being very busy as they had many additional roles (such as a safety rep, first trainer etc), as well as holidays and illness. Therefore, there were times translators weren't available and communications were made through a 'funky chicken dance' or many noise, hand and body movements. This was far from ideal as it led to confusions and difficulties in intervening in a positive manner (stop symbols can seem abrupt).

Different groups of nationalities had different ways of working despite all having to comply with UK health and safety standards. This led to: conflicts on what was safe, 'holes' in the procedures, unintentional unsafe acts due to lack of knowledge and misunderstandings, which in some cases, led to tensions between parties. There was confusion in deeming competence of the workers and those that were not perceived satisfactory were sent home, which combined with workers being away from home and wanting to return, led to a high turnover. There were also suggestions that the workers lacked experience. Communicating acceptable work practices, changing work practices and keeping consistency throughout the project was a significant challenge.

Appointing a nationally diverse workforce can create significant health and safety challenges and problems. In this study migrant workers were initially a cheap option, but also a greater risk, and significant time and resources was required in an attempt successfully manage the communication issues and the different working practices. The use of migrant workers, who also acted as translators, was an inflexible and far from ideal approach that led to a 'funky chicken dance' in order to communicate.

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MOVING FROM STATIC TO DYNAMIC MEASURES OF BIM SUCCESS

Ruth Dowsett¹ and Chris Harty

School of Construction Management and Engineering, University of Reading, Reading, UK

Existing methods to measure the quantitative and qualitative benefits of building information modelling (BIM) have predominantly been designed to support the business case for the adoption of BIM and in most cases have proven its benefits. However, following the government mandate of Level 2 BIM on all centrally procured construction contracts by 2016 BIM has continued to gain momentum. As such, the motivation to adopt BIM is less about return on investment and more about competitive advantage within an industry where clients are becoming increasingly aware of the benefits BIM methodologies can bring to their projects. Accordingly, measurement methods should also change tack and refocus attention from static metrics associated with action that has already taken place to the ongoing activity of implementation. The approach to performance measurement within this paper is predicated on the understanding that project success and its measures are indicative of the configuration of BIM as a system that stretches beyond the boundaries of technology application. The Delone and Mclean Information System Success Model has remained a useful tool to assess the successful implementation of information systems since its introduction in 1992. In this paper, the authors extend its use to assess the success of BIM implementation on a large urban regeneration project to provide a means for effective system improvement, further realisation of benefits, and improved return on investment (ROI) in subsequent phases or projects. An interview protocol developed using the six constructs of the D&M model was used to assess the experience of ten design team members using BIM to coordinate a specific design component within a large urban regeneration project. Through the thematic analysis of project team interviews, normative BIM benefits to design processes were identified; however, these benefits have highlighted an inextricable link between the successful implementation of BIM and project context. Late engagement of BIM consultants, uncertainty over strategy intentions, learning curve of the software, parallel 2D and 3D design development, and programmatic issues associated with early clash detection have been recognised as limiting factors to BIM benefits realisation on this project.

Keywords: benefits evaluation, BIM, implementation.

INTRODUCTION

Building information modelling (BIM) is the process of designing buildings using a variety of information communication technology (ICT) tools (3D CAD, databases, interfaces) and associated business processes to represent and manage information within a 3D model (Davies and Harty 2013). Moreover, BIM is synonymous with collaboration, which in the context of construction will inevitably require the reconfiguration of complex set of actors, technologies and activities into an information system (IS) that can facilitate this.

¹ Ruth.Dowsett@excitech.co.uk

The list of purported benefits of BIM is extensive; improved quality control, on-time completion, reduced waste through reduction in re-work from early coordination, improved scheduling, early clash detection, productivity improvements, increased opportunities for pre-fabrication, fewer requests for information (RFIs), fewer change orders, early design error detection, less skilled workforce required reducing costs, improved safety performance through construction simulation, interoperability – technically, culturally and organisationally, and more (Barlish and Sullivan 2012; Azhar 2011). But the validation of these benefits is limited with only a small number measured in isolation (RFIs/no. of clashes/change orders) to quantify the ROI of implementing BIM (Barlish and Sullivan 2012; Becerik-Gerber and Rice 2010; Giel *et al.* 2010). Furthermore, methods to measure the benefits and ROI were specific to the context of the project and organisational strategy making them unrepeatable. This paper argues that whilst these measures are valuable in their own right they understate the process of IS reconfiguration required to achieve the outcomes they are measuring. The research problem this paper aims to address is the investigation of a more holistic approach to measurement that pays closer attention to the process of implementation as a means to improve the benefits of BIM.

LITERATURE REVIEW

Historically, IS performance measurement, within most domains, has employed relatively prescriptive and instrumental methods to develop a business case for system adoption or to determine a suitable implementation strategy at an individual organisational level. Within the context of BIM-enabled construction, the existing approaches to measuring the benefits of BIM also reduce the measures of success down to technically discrete variables. To mean they are universal, impose a predefined value of BIM for the user to interpret, require routine practices that focus on stability and control whereby meaning remains static and consequently system configuration adapts to the measures. Measurement in isolation within the context of construction can be too rigid to fulfil the fundamental purpose performance measurement, which is: to discover and verify gaps between actual and required performance, to improve individual, organisational and implementation management performance capabilities such as critical management support, resource allocation and technical support in order to close that performance gap. In this instance, evaluation in conjunction with measurement is potentially a better approach. Evaluation is context dependent and can be self-determined by the users; pertinent information emerges, system value is created and unanticipated information is essential for adaptability and growth. Furthermore, the value of the system to the users evolves and system configuration co-adapts with the measures required to assess performance (Wheatley and Kellner-Rogers 1999). More specifically, a shift in focus to IS performance measurement at project level supports technology specification alongside collaboration and information sharing necessary to realise the purported benefits of BIM (Dehlin and Olofsson 2008).

Cost and time parameters usually trump value and quality of design processes, in part attributable to their ease of quantification but also to the normative vision of profit as a measure of business success. Although they are important in their own right cost and time parameters are dependent on the value and quality of design processes that are less comprehensively understood, more difficult to define and measure, and require wider consideration of their impact within social, economic, technical and ecological problems to determine their success. Improved processes that utilise innovative tools and technologies to meet triple-bottom-line requirements are important to avoid cost

and time overruns. Yet, the complexity, uncertainty, instability, uniqueness and value-conflict associated with traditional construction do not allow a measure-manage approach to be effectively utilised. Especially within the context of the early implementation of BIM; its unbounded (Harty 2005) and systemic (Taylor 2007) nature, and the resulting complex assemblage of actors, technology and activities change throughout projects making it difficult to agree a definite criterion of measurement without underrepresenting the system and contorting performance to that which is being measured (Gann and Whyte 2003). Conversely, if the determinants of success (for example, the level of actor-technology engagement required to reduce RFIs) can be identified these may be leveraged and controlled to achieve the success measure, such as providing a technical support network to facilitate the successful use of the technology.

Gann and Whyte (2003) define a rational-adaptive approach that accepts complexity and the difficulty in understanding future trends, but through the use of tools and techniques that map past, present and possible future outcomes to assist in developing a general course of action make success a more probable consequence. With regards to BIM some elements are easily measurable, such as the number of requests for information (RFIs), clash detection results, etc. but what these measures actually represent is the mutually dependent production and use of information, the success of which is context reliant and consequently very difficult to measure. Using the tangible inputs and outputs of BIM-use as a proxy for process investigation presents a rational-adaptive approach to measurement and a more meaningful representation of BIM success. Moreover, by conceptualising BIM as an information system and adopting a rational-adaptive approach to measurement, frameworks of analysis can be rationally appropriated from the IS discipline. The DeLone and McLean IS Success Model (2003) has been extensively used and evaluated (Myers *et al.* 1997; Seddon *et al.* 1999; Petter *et al.* 2008) and may prove significant when attempting to measure the success of BIM implementation. The DeLone and McLean (D&M) model was developed in response to a lack of defined information systems success measures that are compounded by indirect human, organisational, and environmental factors. They developed a taxonomy of IS success identifying six variables of interdependency; Systems Quality (SQ), Information Quality (IQ), Intention to Use (IU), Use (U), User Satisfaction (US) and Net Benefits (NB) (DeLone and McLean 2003).

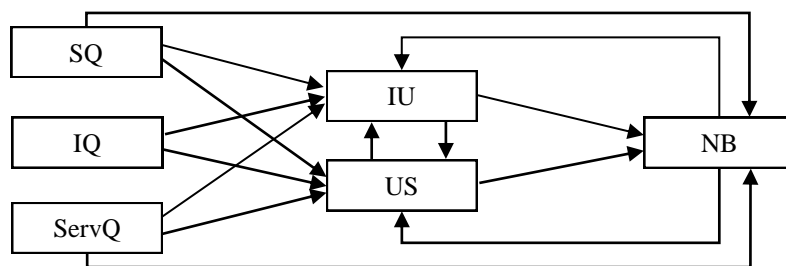


Figure 7: DeLone and McLean IS Success Model (2003)

As a process model, it identifies the development of a system, the use of a system, and the consequences of system use whilst supporting contextual variance, as such the authors encourage and expect different appropriations to maintain utility of both constructs and measures. Therefore, assessing the relationships between System Quality, Information Quality, Use, User Satisfaction and Net Benefits throughout a BIM project provides an ideal context within which to test the model's effectiveness in assessing BIM implementation success. It is also an opportunity to assess whether the improved information quality and coordination associated with BIM use improves

design processes and which variables in what sequence constitute benefit causality and augmentation.

RESEARCH APPROACH

Within this study a series of semi-structured interview questions were developed to investigate each of the six quality constructs of the Delone and Mclean model made specific to BIM through a critical review of the literature. For the purposes of this study, Intention to Use and Use constructs are integrated into Information Use (IU). Questions regarding SQ referred to the technical quality of the BIM system (e.g. efficiency and functionality); IQ referred to system outputs (e.g. relevance and informativeness); ServQ referred to system support (e.g. adequate training and protocol effectiveness); IU referred to task based activities (e.g. nature and appropriateness of use); US referred to the attitude of the user (e.g. enjoyment and decision-making satisfaction); and NB referred to improvements in individual and organisational capabilities (e.g. overall productivity, cost/time savings). Individuals were selected based on the significance of their design processes and information production to the successful design of the project's Cross Laminated Timber (CLT) component (described in the following section). Transcripts were then thematically analysed to provide a narrative of system implementation and specific benefits within each construct were identified based on the BIM benefits literature and classified referring to the D&M Model taxonomy of IS success.

Table 1: Interviewee Roles/Company

Company	Role
CLT Contractor	BIM Manager / Project Manager / Project Director
Client	Project Designer / Development Project Manager / Design Manager
MEP Engineer	BIM Manager
BIM Consultancy	BIM Consultant

By focussing on one design component, a reasonably comprehensive collection of qualitative data has been achieved, allowing a detailed analysis of BIM system success in supporting the design of CLT. It also provides a context-specific means to examine the relevance of the Delone and Mclean IS success model in BIM benefits measurement. In short, the first objective in studying design processes associated with CLT is to develop a methodology for capturing the performance of BIM implementation within a project. The second objective is to explain the influence of BIM methodologies on existing design and construction processes, and to investigate the idea that the successful implementation of BIM (the reconfiguration of actors, processes and technologies) is dependent on the organisational context in which it is applied. The actors, technology and processes that are self-evident throughout the process of mapping the case study are loosely categorised into five of the six constructs - User Satisfaction is difficult to ascertain at the beginning - to compare to the interview findings. After which, less obvious aspects of system configuration that are integral to the successful implementation of BIM are discovered, categorised into the model constructs and used to identify significant interdependencies of system success.

CASE STUDY

The case study project is the first phase of a five-phase urban regeneration project providing residential units, retail and business space, community, culture and leisure

space, an energy centre, a park and public realm located in London. At the time of interviewing, the project was moving through technical design (Stage E) to the next milestone of first package issue for tender in August 2014. As client, contractor and operator, the project owner aspires to maintain the value of information produced throughout the project to improve the operation and maintenance of the buildings at handover. As one interviewee described ‘unlike a lot of developers, we actually retain the building, and we run it’. A critical aspect of the design in meeting the environmental targets aspired to by the client is the use of CLT as a carbon negative material to replace traditional materials such as steel and concrete where feasible. The intention is to use the material cost effectively, taking into consideration its constraints on a project of this type to ensure buildability and to avoid negative impacts on project programming. However, it brings with it a set of new coordination issues alongside the implementation of BIM, such as; the need for robust front-loaded design collaboration amongst interfacing disciplines and completed designs ahead of start on site to allow for offsite manufacture (BRE, 2011).

Mobilising the model - System Scoping

In terms of System Quality, the client has specified the use of Revit to enable model coordination and to allow model interrogation/clash detection in NavisWorks. The design team members must refer to the model and information development protocols published by the client to meet the level of Information Quality they aspire to, which is models quality assured in graphical, information and Level of Definition (LOD) content as defined in the BIM Execution Plan (BEP). With reference to Support Quality, the client has appointed an external BIM consultant to develop the BEP that contains the protocols, methods and workflows for the design team to follow for this stage of the project. With regard to Information Quality, the client expects the design team to share, distribute and re-use the models and their associated data and documentation for the purposes of 3D coordinated model reviews leading to Net Benefits associated with Clash resolved models, such as reduced waste/RFIs etc.

FINDINGS

Generally, the technical aspects of the BIM system are well regarded. System functionality is good in terms of improved design capabilities in the form of faster object manipulation supported in its ease of use. Interoperability between systems is good for those that use them; data is accurate, current and relatively easy to access and whilst the interviewees believed that design solutions had improved, the project suffered programme delays as a direct result of BIM implementation. The details of which are described in the following paragraphs.

Late engagement of BIM Consultants

BIM is a relatively new concept for many members of the design team and the purpose of appointing the BIM consultant was, in part, to develop consistent BIM use.

‘...my involvement has been...getting involved with workshops, we then just try and help them establish the brief and just listen to them and see what they really want. And I think that’s, even today...that brief’s still evolving.’ (BIM Consultant)

However, late engagement of the BIM Consultant during the design development stage (Stage D) and uncertainty surrounding their scope of services has reduced their ability to inform the effective implementation of BIM. In hindsight, information requirements could have been compared against existing technical capabilities to develop an implementation strategy that considers imbalances in technical capability.

Furthermore, strategic intention may have been better understood or developed through earlier engagement with the BIM consultant to develop and implement the Employer's Information Requirements (EIR). A number of workshops were carried out to establish the clients requirements at the point of their engagement and an EIR was created but this happened too late for it to be effective.

'Quite late on we created an EIR for them, but the EIR hasn't been used on this project.' (BIM Consultant)

At the point of interview it was still in development and combined with the fact that the scope of services for each project team member had already been defined meant that it was not used on this project. In a sense, the project is being used as a learning curve for the client and the lessons gathered from this project should be used on subsequent phases, though in reality this does not appear to be happening. Subsequently, the brief was too vague which perhaps had a knock-on effect to consultant buy-in and adoption of the BIM processes. A vague brief from the client may indicate a vague understanding of the requirements for the successful implementation meaning that the groundwork that must be in place to enable the use of BIM throughout the project lifecycle is not there. Scope of appointments did not contain the relevant information and consultants found themselves being asked to deliver BIM related work that they may not have factored into their bids, therefore providing a reasonable basis from which to resist additional work associated with it. Furthermore, the BEP was introduced during the detailed design stage when traditional processes were already embedded within the project. The consequence of which is resistance at a local level, specifically from the MEP engineers, of which MEP BIM Manager believes could be overcome with a better understanding of BIM related documentation to motivate the adoption of new working practices:

'...I do think the BIM execution plan is not often understood by engineer...if they had more of an understanding of what's happening such as levels of details and when their due on a project and so they understand that...pipes can be a generic size...but then as you move up the chain you start to refine that...' (MEP BIM Manager)

In this instance, whilst the BEP was considered an enabling factor for successful BIM use late engagement of the BIM Consultants, as a negative aspect of Support Quality, affected Information Use in that they could not advise the client on aligning the project programme with BIM methodologies.

Uncertainty surrounding strategy intentions

Attitudinal changes to the underlying principles of coordinated design delayed the effective use of the model. As the client Project Manager alludes to:

'...I get the feeling that a lot of the design team are holding back on wanting to send information out, because it might be wrong...hanging onto it and trying to refine it yourself doesn't actually benefit the wider team...' (Client Project Manager)

This is potentially a consequence of poor dissemination of strategic intention resulting in design team expectations of information delivery out of alignment with client expectations of what was to be received:

'...in terms of strategic intention, I think there's definitely, there's a gap. There are certainly different aspirations from within the design team that aren't necessarily aligned with overall (Client) aspirations for using BIM on the project.' (Client Project Manager)

As a negative aspect of User Satisfaction, dissemination of strategic intentions negatively affected Information Quality and subsequently Information Use.

Learning Curve of the software

Without a set of clear strategic intentions it is very difficult for the BIM technologies to be adopted effectively since the design team require a period of adaptation that client has not factored into the design process:

'...clients see the benefit of using the tools but usually they don't appreciate the difficulty to have all partners using those tools...sometimes the project has specificities that will require some adaptation period...' (CLT Project Manager)

This means that software functionality has been limited to 3D design for the purposes of coordination rather than discipline specific analysis within the modelling programme and the impact of this on each discipline differs. For example, integrating a coordination stage within the CLT consultant's workflow was not particularly difficult. An advantage specific to their work package is that they only needed to indicate where their walls need to be to show the impact on other disciplines:

'...once we've passed that stage we'll keep within the confines of our areas and anything that happens in there won't affect that outside of there...it's a comfortable position to use BIM for us knowing that more complex details we do it outside of it.' (CLT BIM Manager).

In addition, the organisation was already in a position to adopt the new technology and its associated processes with relative ease since the project manager had extensive experience in the use of Revit and understood the methodologies that need to be in place to utilise the systems capabilities.

'...I know Revit quite well, I've done studies on it, I've taught it, I was able to sit down, spend a bit more time at the beginning thinking about how we were going to do this...setting out a plan of how we were going to get each of these things put together and how we were going to incorporate each piece of information.'

Conversely, the MEP BIM Manager, whilst convinced of the positive changes to their workflows, they are frustrated by the reluctance of Engineers to submit unfinished solutions necessary to fully realise the benefits of coordinated design.

'They don't understand that it's much easier once something's in to amend that item which doesn't require 50 drawings changing, you do it once on the model, all drawings update themselves, everything is changed.' (MEP BIM Manager)

In this respect, inconsistent technical capabilities as a negative measure of User Satisfaction identifies an interdependency with Support Quality and would indicate a need to assess user capabilities specific to the client aspirations of BIM prior to project commencement.

Parallel 2D and 3D design development

An important factor affecting the success and use of BIM within this project has been related to the concurrent 2D and 3D design development. In addition to the 3D system and design development requirement a concurrent 2D drawing issue, commenting and design development process is running. As such, the workload has doubled for many of the disciplines newly adopting 3D software, specifically for the CLT designers:

'...what we understood was that we were to continue as we would normally as a consultant developing the design through workshops and two dimensionally but there

would be this concurrent system being run by (the BIM Consultant)...to start with it occurs as double the work for us...’ (CLT, Project Director)

Specifically for the CLT designers the area in which they would see significant benefit in having coordinated models is with an early clash detection process with M&E. As a prefabricated element, it is costly to make changes on site therefore it is important to resolve clashes earlier than in other forms of construction. However, the benefits of BIM have not been fully realised since the coordination and clash detection processes are:

‘...happening later in the 3D process than would be useful for our design development...the coordination of the project was slightly different we could be using, and I think we’re getting there now, the 3D process from which 2D can be taken.’ (CLT, Project Director).

In spite of the reduced benefits for the CLT contractors, the collaboration between the design team has happened earlier in the programme with most impact on MEP design processes. The MEP BIM Manager referred to this process as ‘reverse engineering’, predicting the extent of services they will be designing inside the building to determine builders work hole sizing within the slabs for early commencement on site. Without the use of the BIM protocols to deliver quality information for coordination, the interviewee did not believe it would have been possible to achieve the same level of coordination:

‘I think without BIM it would have been an easy task to do but, at the same time, it would have been very wrong. (MEP BIM Manager)

In this respect, Information Quality whilst good and a consequence of good Support Quality has not been utilised effectively and limited Information Use. Responses regarding User Satisfaction indicate that users were unaware of what they should be delivering and when, consequently an improvement in the clarity of BIM deliverables as a measure of Support Quality would be beneficial to the success of the system.

Programmatic issues

The standard project goals of on time and on-budget completion that are inherent in a traditional approach were applied to this project and as the CLT Project Manager describes the transition to BIM being the lead in coordination has never been fully made. Especially if a consistent understanding across the design team over what the model will be used for does not exist:

‘...BIM is always trying to catch up...in this project...especially in terms of the coordination of services there wasn’t full understanding at some point that BIM will take the lead in terms of coordination.’ (CLT Project Manager)

Moreover, when a consensus of understanding finally transpires the impact on the project programme is negative. From the perspective of the CLT engineer, initially the MEP engineers understood the technology to be used as a ‘...recoding tool to see in the end of it and not as a working tool.’ this coincides with the BIM consultants observations of process inefficiencies within the MEP discipline that ‘...they’re modelling and they’re producing 2D drawings...’, and also the Client Project Manager’s ‘...they still draw their designs and work stuff up in 2D, and then translate it into 3D.’ Therefore, when the design team reaches a point of consistent technology adoption and utilisation there is a sudden increase in design capabilities that are not considered against the project programme:

'...this lack of preparation or understanding maybe of the way it works, BIM works, has produced delays on the programme that hasn't been fully assessed.' (CLT Project Director)

In this instance, although System, Information and Support Quality positively affect the design solution through clash detection and coordination the project programme has limited their benefit on the prefabrication of CLT. Users advocated the inclusion of model milestones within the design programme to ensure high-risk interfaces are resolved earlier and negatively associated their absence with Support Quality.

DISCUSSION AND CONCLUSION

We argue that a much more nuanced and qualitative understanding of measurement is required to examine the benefits of BIM, which explicitly recognises its position as a proxy for more complex interactions. This paper has explored the utility of the Delone and Mclean IS Success Model as a means to achieve this. By categorising BIM into a system of six quality constructs the state and circumstances of its use can be investigated systematically to determine interdependencies significant in achieving the aspired project benefits. Empirical evidence can be systematically collated to develop a reasonable challenge to existing attitudes and embedded practices that might be preventing technology adoption, process change and practice change. Figure 1 shows the use of the model focussing in on one benefit described by the interviewees. Early design issue identification has allowed the client to implement contingency strategies earlier in the design process. By using the D&M model, positive and negative impacts of this can be identified and steps can be taken to reconfigure the BIM system toward a more positive outcome. Aspects of System Quality and Information Quality shown in Figure 2 indicate a positive relationship with early design issues identification. Faster communication of easily interpretable information means that interdependent design elements that would normally be configured later in the project can be adjusted earlier to reduce risk, time and cost, improving the final design solution. However, without an EIR or a Model Element Table (MET) some issues can be identified that may not necessarily be of critical importance. This puts added pressure on the design team and delays the delivery of packages. Despite this, the protocols and processes that are defined within the BEP do make a supporting contribution to this factor of Information Use.

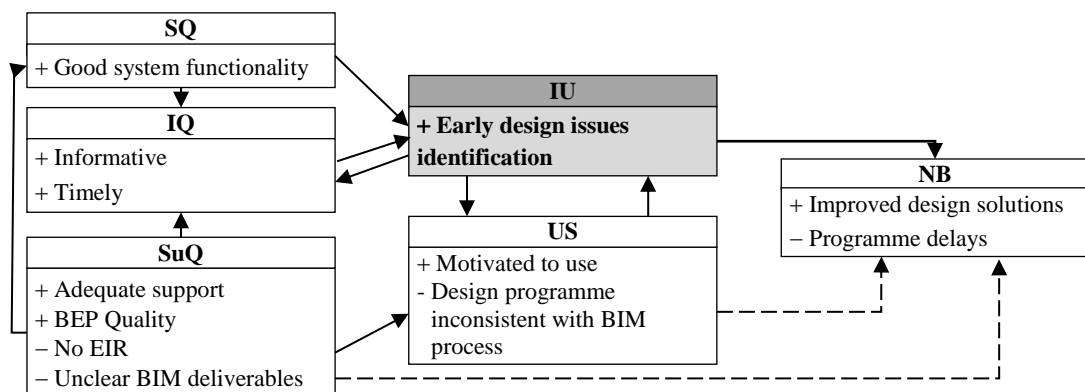


Figure 2: System interdependencies - Early design issue identification

The intention is that the method and model applied in this instance can be used on subsequent projects to comprehensively inform and support change management initiatives that are tailored to stakeholder organisational circumstances. Through using the Delone and McLean model as a means to develop the interview protocol

circumstances of system configuration and their impact on performance could be ascertained. The results of which have been useful to the BIM consultant in advising the client how they should approach the implementation of BIM on subsequent phases. Further work would include iterative application of the model at regular intervals within the project. However, it should be assumed that this is subject to change depending on criticality and it is anticipated that lessons learnt relevant to project success will cumulatively lead to implementation success.

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BIM ROADMAP STRATEGIC IMPLEMENTATION PLAN: LESSON LEARNT FROM AUSTRALIA, SINGAPORE AND HONG KONG

Nor Asma Hafizah Hadzaman¹, Roshana Takim and Abdul Hadi Nawawi

Faculty of Architecture, Planning and Surveying, Universiti Teknologi MARA (UiTM), Shah Alam, Malaysia

Information and technology has produced large changes to construction industry and leads to innovative nations globally. Building Information Modeling (BIM) is one of the IT platforms to rely on the process of planning, design, construction, and operation of a building in 3D dimension to promote collaborative and integration between the parties in the construction projects environment. BIM is defined as a parametric modeling to support project life cycle through relevant data and information shared among project stakeholders. BIM roadmap is a strategic plan by the government of Malaysia to ensure a wider adoption of BIM embraced among industry players. However, despite the existence of strategic implementation plan recently developed by the Government of Malaysia through CIDB, the implementation plan has less emphasis on strategic analysis elements (i.e., capacity, support, and value). Hence, the objective of this paper is to incorporate the strategic analysis elements (i.e., capacity, support, and value) in the existing Malaysia BIM roadmap pillars based on the lesson learnt from Australia, Singapore and Hong Kong. A qualitative research technique was employed in the form of document analysis for the establishment of Malaysia's BIM roadmap, while a formal workshop with experts from representatives of Public Work Department and Ministry of Health (directly involved in the first BIM Malaysia's pilot project of National Cancer Institute) for the establishment strategic analysis elements (i.e. capacity, support, and value) to be embedded in the roadmap. The findings suggest that the strategic analysis elements (i.e., capacity, support, and value) to be incorporated in the existing Malaysia's BIM roadmap has seven pillars (i.e., standards and accreditation, collaboration and incentives education and awareness, national BIM library, BIM guidelines, special interest group (SIG); research and development (R&D). The outcomes could act as a guideline to industry players for future development of BIM-based projects in Malaysia.

Keywords: Malaysia's BIM roadmap, BIM, document analysis, implementation plan.

BIM IN MALAYSIA: AN OVERVIEW

Most of Malaysia construction projects are based on the traditional construction process which related closely to the issues of reworks, time delays, rising cost, lack of communication and coordination (Nawi *et al.* 2014b). As such, according to Nawi *et al.* (2014a), an integrated approach is one of the solutions in design and construction to minimise the fragmentation gaps. This action was a result of the client/government's awareness of the potential of BIM to reduce construction cost and avoid design problems in planning phase (Latiffi *et al.* 2013). Building Information

¹ norasmahafizahhadzaman@yahoo.com

Modeling (BIM) is one of the IT platforms to rely on the process of planning, design, construction, and operation of a building in 3D dimension to promote collaborative and integration between the parties in the construction projects environment. According to Kestle (2009), the lack of project pre-planning and uncertainty of clarity in project process integration by the clients were leading to misinterpretations and miscommunications of project outcomes. This phenomenon was plague by traditional procurement process when the client appoints the consultant to act on his behalf to produce the design, and contractors to supervise the construction phase. BIM offers an integrated solution to the management and communication problems to solve the problem with traditional procurement process. Moreover, BIM is increasingly used as an IT support for complex construction projects (Latiffi *et al.* 2013), in particular for Malaysian construction industry. The notion drives Malaysian Government to formulate Malaysia's BIM roadmap. The purpose is to align BIM implementation with the national strategy to 'respond the changes in construction demand as envisaged in Malaysian Vision 2020 through BIM adoption'. Following the footsteps of various developed countries, Malaysia has adapted BIM practices into legal project through various public and private projects (Latiffi *et al.* 2013; Zakaria *et al.* 2013). Nonetheless, the practice of BIM in Malaysia and other developing countries are considered as far behind in comparison to the developed countries (Latiffi *et al.* 2013; Zakaria *et al.* 2013).

United Kingdom, Australia, Singapore and Hong Kong are the four countries that are considered to have effectively implemented BIM due to the robust application of public and private publications, the meaningful strategies of alternatives and cumulative impacts in the BIM project report submitted/published (BCA 2011; Zakaria *et al.* 2013). Many researchers have discussed the best practice examples and maturity stage for BIM that describes the utilization of BIM process in construction projects (Eastman *et al.* 2008). Recent exemplar development includes the BIM roadmap implementation in UK construction industry that tackles the guidance at strategic and operational levels in BIM implementation (Khosrowashahi and Ariyaci 2012). Moreover, the BIM strategies and involvement of government and private sectors role to adopt BIM are being researched in Australia and Hong Kong (Staub-French *et al.* 2011), Singapore and UK (Staub-French *et al.* 2011; Zakaria *et al.* 2013). Nowadays, emerging from the various initiatives around the world, BIM approach has been proved to deliver productivity in the Architectural, Engineering, and Construction (AEC) industry. In comparison with the four countries mentioned by BCA (2011) and Zakaria *et al.* (2013), the level of adaption and practice of the implementation of BIM in Malaysia is rather questionable. Hence, the focus must be given to become competitive with other developed countries.

According to Latiffi *et al.* 2013, and Zakaria *et al.* 2013, Malaysia is still struggling in adopting BIM process which currently focusing to move from 2D working environment to 3D working environment. However, based on the development of Malaysia's BIM roadmap (CIDB, 2015), the committee are perceived to benchmark BIM practice with three countries which is Australia, Singapore and Hong Kong for the development of a Malaysia's BIM strategic implementation plan. Undoubtedly, there must be some risks that need to be faced when implementing a new technology as such BIM application. Due to that, government of Malaysia play a role to drive and assist the construction companies through the establishment of BIM roadmap that beneficial to all parties involved. As such, it is necessary to establish a common definition of maturity for BIM roadmap. Due to that, Succar (2009) creates a BIM

maturity stages for BIM implementation by subdividing the implementation plan into three stages. Referring to Figure 1, off late it can be seen that the maturity level of BIM in Malaysia is still at early stage compared to Australia, Singapore, and Hong Kong. The BIM maturity stages provide a systematic framework and used as a benchmarking tool to develop the Malaysia's BIM roadmap. This implies that, it is essential for the Malaysian construction industry to access the strategic analysis elements (i.e., value, support and capacity) to be incorporated in the BIM strategic implementation plan of seven pillars (i.e., standards and accreditation, collaboration and incentives, education and awareness, national BIM library, BIM guidelines, SIG, and R&D) for a successful development process.

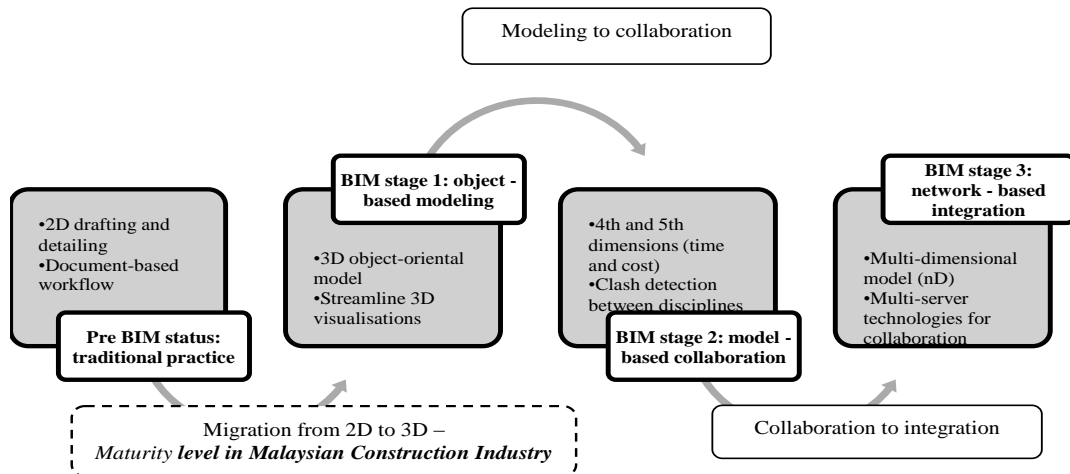


Figure 1: BIM maturity stages (Source: Succar, 2009)

Hence, the objective of this paper is to incorporating the strategic analysis elements (i.e., capacity, support, and value) in the existing Malaysia's BIM roadmap pillars based on the lesson learnt from Australia, Singapore and Hong Kong.

RESEARCH METHODOLOGY

Philosophy is a belief of the way in which data about a phenomenon is identified, gathered, analysed, and presented. Philosophical stance needs to be laid in a strong foundation of assumptions relating to epistemological undertakings, ontological assumptions, and axiological purpose (Mohd-Tobi 2013). The paper adopts an ontological position that inclines towards constructionism that is to seek the BIM roadmap strategies and providing insights on the strategic analysis elements. According to him, interpretivism philosophy need small samples and type of research strategy is in-depth investigations to achieve agreement on the description of the issue. Thus, the interpretivism philosophy as qualitative research technique (phenomenological research) is employed for data collection in the development BIM and later is useful in BIM roadmap development to ensure a wider adoption of BIM among industry players.

In the development of Malaysia's BIM roadmap of seven pillars, a pre-determined BIM committee is established. The committee consists of relevant government agencies (i.e., Construction Research Institute of Malaysia (CREAM), Construction Industry Development Board (CIDB), Cawangan Pengurusan Projek Kompleks (PROKOM), Implementation Coordination Unit (ICU)), professional bodies (i.e., Royal Institutions of Surveyors Malaysia (RISM), Pertubuhan Arkitek Malaysia (PAM), Malaysia Asset and Project Management (MAPMA), Association of Consulting Engineers Malaysia (ACEM)), private sectors and academia (Universiti

Teknologi MARA). 5 brainstorming sessions and 2 workshops were conducted for a period of 12 months organised by CIDB and CREAM to gather relevant and precise data for the development of the Malaysia's BIM roadmap. Three countries (i.e., Australia, Singapore and Hong Kong) were selected for the benchmarking process through a document analysis process as depicted in Table 1.

The second part of the research method is to incorporate the strategic analysis elements (i.e., capacity, support, and value) that are required to be embedded in the Malaysia's BIM roadmap. In this case, a formal workshop were deployed with experts from representatives of Public Work Department and Ministry of Health through a set of questionnaires to respondents who are directly involved in the BIM-based project of National Cancer Institute (NCI) of Malaysia.

Table 1: Existing BIM Roadmap Documentations

	Country	Name/title	Author (Year)
1	Australia	National Building Information Modelling Initiatives, Volume 1: Strategy	buildingSMART Australasia (2012)
2	Singapore	Singapore 2nd BIM Roadmap	BCA & Wah (2014)
3	Hong Kong	Final Draft Report of the Roadmap for BIM Strategic Implementation in Hong Kong's Construction Industry	HKCIC (2013)

In order to reinforce the findings, separate face-to-face semi-structured interview sessions were conducted with five prominent respondents who are champion and directly involved in this BIM-based project. Respondents for this study were from the middle and top management levels. The middle and top management were chosen for the fact that these levels of management have the mandate whether to implement BIM or not in their organisations as asserted by Smith and Tardif (2009). Majority of respondents has more than 10 years' working experience in the industry and an average of 7 years in BIM (since 2007). The interviews focused on BIM roadmap pillars based on the strategic analysis elements (i.e., capacity, support, and value). The formal workshop discussion was held on the 3rd of April 2015 for a period of two hours deliberation. The sampling is shown in table 2.

Table 2: Respondent Position and Background - NCI Project

	Position	Respondent Background
P1	Top management level	Civil Engineering
P2	Top management level	Architect
P3	Top management level	Civil engineering (Structure)
P4		Failed to participate
P5	Middle management level	Architect
P6	Middle management level	Architect

DISCUSSION ON DOCUMENT ANALYSIS

Development of Malaysia's BIM Roadmap

Table 3 shows the BIM roadmap based on the lesson learnt from Australia, Singapore, and Hong Kong. As mentioned previously, these countries were selected for benchmarking comparison for the fact that they are having a good track record of performance. The comparison addresses the trend of BIM roadmap based on Strategic Implementation Plans of Australia's practice (known as work programs), Singapore (known as strategies), Hong Kong (known as perspectives), and Malaysia (known as pillars). These BIM roadmaps are discussed in turn:

The Australia’s BIM Roadmap

The Australia’s BIM Roadmap by the buildingSMART Australasia summarises the National BIM initiatives work programs. BIM development in Australia was drive by public organisation and to date; BIM is starting to take off. Both governments and industry associations are urged to speed up the process. The strategic implementation in Australia developed six (6) work programs as shown in table 3. Compared to Singapore and Hong Kong, BIM in Australia used time line program for the roadmap implementation plan and urge stakeholders to adhere to the target date. In spite BIM in Australia addressed on the six work programs as mentioned previously, Australia’s BIM roadmap neglect to highlight on incentives to BIM adopters.

Table 3: The Strategic Implementation Plan of Australia, Singapore, and Hong Kong

Strategic Implementation Plan		
Australia (6 Work Programs)	Singapore (6 Strategies)	Hong Kong (9 Perspectives)
1) Procurement	1) Drive BIM collaboration throughout value chain	1) Collaboration
2) BIM Guidelines	2) Building BIM capability of specialist contractors	2) Incentive and proven benefits
3) Education	3) New training programmes at all levels	3) Standard and common practice
4) Product data and libraries	4) BIM research and development	4) Legal and insurance
5) Process and data exchange	5) BIM for Design for Manufacturing and Assembly	5) Information sharing and handover
6) Regulatory framework	6) BIM for facilities management	6) promotion and education
		7) Sufficient digital capability and vendor support
		8) Risk management
		9) Global competitiveness

The Singapore’s BIM Roadmap

Currently, Singapore is working on developing the second BIM roadmap with focused to transformation process, research and development and BIM application in facilities management as compared to the previous Singapore’s BIM roadmap developed in 2010 (Wah 2014). The BIM roadmap of Singapore is quite similar to the Hong Kong’s BIM roadmap which takes into consideration BIM collaboration, R&D, barriers, and productivity achievements. The strength of Singapore’s BIM roadmap is two folds: firstly, Singapore using BIM through CORENET (Construction and Real Estate NETwork). The Building Construction Authority (BCA) is the first multi-agency in the world that implements BIM electronics submission (BIM e-submission). Secondly, the roadmap is focussing on Design for Manufacturing and Assembly (DfMA) for off-site manufacturing and on site assembly and installation (Boothroyd 2011). The BCA long term goal is to create a highly integrated and technology advanced application in construction industry which led by the progressive firm and supported by skilled and competent workforce in 2020. Under the strategy plan, BCA has set a target of getting the construction industry to use BIM by identification of six (6) strategies in BIM roadmap as shown in table 3.

The Hong Kong’s BIM Roadmap

Following the perceived success of BIM implementation in Australia’s and Singapore’s BIM roadmap, Hong Kong’s BIM roadmap was published in 2014 despite BIM has been introduced since 2006. The Hong Kong’s BIM Roadmap by the

Working Group on Roadmap for BIM Implementation established under the Committee on Environment and Technology of the Construction Industry Council (CIC) outline views of the Working Group on the strategic implementation of BIM in Hong Kong's construction industry. Since then, the use of BIM have been spread involving various types of projects, i.e. commercial and industrial. Hong Kong's Housing Authority has set a target to apply BIM for new projects by 2014/2015. However, a timeline is not included in the roadmap as it will proposed after the Hong Kong's industry understand the benefits of BIM achieved. The roadmap focused on nine (9) areas and seventeen (17) recommended initiatives as shown in table 3. The strength of Hong Kong's BIM roadmap are: the BIM roadmap emphasises on incentives and proven benefits to BIM adopters, adopting risk management in the perspectives, and global competitiveness.

The Malaysia's BIM Roadmap

In the context of Malaysia, the strategic implementation plan through the establishment of seven (7) pillars have been recognised for BIM roadmap via several discussion, brainstorming, and workshop held by CIDB, CREAM and industry players. This roadmap has been published in March 2015 by CIDB, Malaysia (Malaysia BIM Center). The seven pillars include: standards and accreditation; collaboration and incentives; education and awareness; national BIM library; BIM guidelines and legal issues; special interest group; and research and development as described in Table 4.

Table 4: Spectrum of Malaysia BIM Roadmap Pillars upon Best Practice

Malaysia (7 Pillars)	Strategic Implementation Plan		
	Australia (6 Work Program)	Singapore (5 Strategies)	Hong Kong (9 Perspective)
1) Standard and Accreditation	√	√	√
2) Collaboration and Incentives	√	√	√
3) Education and Awareness	√	√	√
4) National BIM Library	√	√	
5) BIM Guidelines and legal Issues	√	√	√
6) Special Interest Group (SIG)		√	
7) Research and Development (R&D)		√	

These pillars are compared to the strategic implementation plan practiced by Australia, Singapore and Hong Kong to trace the similar needs, matching the trend, and clarify the construction practices. It can be seen that the Malaysia's BIM roadmap has incorporated most of the variables amalgamated from Australia, Singapore, and Hong Kong by considering the Malaysian construction practices. This implies that the establishment of the seven (7) pillars is comprehensive and significant. To enhance the Malaysia's BIM roadmap, strategic analysis elements (i.e., capacity, support, and value) should be embedded for future development of BIM process as practiced by Singapore in updating their BIM roadmap.

DISCUSSION ON FORMAL WORKSHOP

Incorporating Strategic Analysis Elements – Capacity, Support, and Value

This section initially presents and interprets the interview findings from the organisations involved in first pilot BIM-project in Malaysia in qualitative method. The implementation of any strategy and guidelines to response to any technological system should accommodate strategic analysis elements in terms of capacity, support,

and value. Every strategy and guidelines has its own purpose to convey it comprehensively, longer-term, or result oriented. For the Malaysia's BIM roadmap to be successful and effective, a strategic analysis of construction management perspectives was found to be useful to capture the organisation readiness that they faced in a more coherent and comprehensive way. Hence, BIM roadmap should deployed these three (3) strategic analysis elements to ensure that the plan derived by the government is worth to all parties involved. Table 5 shows the result of the three (3) strategic elements that are important for Malaysia's BIM roadmap.

Table 5: Result of Semi-structured Interview

Strategic Implementation Plan	Strategic Analysis Elements		
	Capacity	Support	Value
Malaysia (7 Pillars)			
1) Standard & Accreditation	P1, P2, P5	-	-
2) Collaboration & Incentives	P2, P3	P1	-
3) Education & Awareness	-	P3, P6	-
4) National BIM Library	P1, P2	P1	P1, P2
5) BIM Guidelines & Legal Issues	P5	P1, P5	-
6) Special Interest Group (SIG)	P5, P6	-	-
7) Research & Development (R&D)	-	-	P2, P3, P6

Unanimously, it was found that the strategic elements mentioned earlier have been asserted by all respondents as the critical elements to be implemented for Malaysia's BIM roadmap which is in line with the framework originated by Leonard (2002; 2008). According to Leonard (2002; 2008), the primary strategic elements are theorised as the key determinants for successful BIM implementation, namely: Capacity: first elements to inquire about whether the existing capacity of the strategy is adequate to carry out the roadmap that is being analysed; Support: people or organisations whose support in term of trust, belief, and shared the same understanding; Value: the creation of outcomes for any program that valuable to the users. As such the seven pillars of Malaysia's BIM Roadmap should incorporate the three strategic analysis elements for developing a feasible and viable successful plan.

Standard and Accreditation

Based on the results, P1, P2, and P5 agreed that a 'standard and accreditation' pillar is an important element in form of unified standard template and certification for completed BIM-based projects to ensure that the Malaysia's practice is aligned with international standards. It is supported by P2 that emphasised on 'the capacity need of people, authority, and time in establishing the national BIM standards and common practices to allow maximum benefit of building information over building life'. This is due to the fact that standards should be developed sufficiently to facilitate a BIM services and directly offering a significant savings in construction as mentioned by Eastman *et al.* (2008).

Collaboration and Incentives

Based on the results, P1, P2, and P5 agreed that a 'standard and accreditation' pillar is an important element in form of unified standard template and certification for completed BIM-based projects to ensure that the Malaysia's practice is aligned with international standards. It is supported by P2 that emphasised on 'the capacity need of people, authority, and time in establishing the national BIM standards and common practices to allow maximum benefit of building information over building life'. This is due to the fact that standards should be developed sufficiently to facilitate a BIM

services and directly offering a significant savings in construction as mentioned by Eastman *et al.* (2008).

Education and Awareness

Furthermore, P3 and P6 indicated that another element worth to consider is 'education and awareness'. According to Khosrowshahi and Ariyaci (2012), education has been an important part in BIM implementation due to the technological and process changes nowadays in the organisations. All the interviewees agreed that all people that involved in BIM require an updated skill for successful implementation. Besides, P6 stated that 'in Malaysia, our BIM maturity is still at awareness level where we need a support from all parties including academia to spread the use of BIM'.

National BIM Library

Meanwhile, P1 and P2 claimed that 'the establishment of BIM library is a role of government to maximise the utility of BIM processes'. It is supported by the statement of P1 emphasised that 'the government should identify a specific BIM platform to suit to Malaysian construction practice'. Based on BCA (2011), 'BIM library' should consist of open standards of generic BIM objects and information for manufactured products that comply with industry practices. However, this requires a collaboration and support from all parties involved. In any case, there is a need to appoint an organisation (i.e., public agency) to monitor the BIM library for universal access.

BIM Guidelines and Legal Issues

'BIM guidelines' relate to the overall process of BIM and 'legal issues' describe in the procurement document and contract provisions. According to P5 'a BIM guidelines must establish a reference document providing the roles and responsible parties, unified methodology and family of BIM components'. Based on HKCIC (2014), legal issues focused on amendments to enable BIM operation in-line with the current contract agreements, scope of work, IP right and data ownership. This statement is supported by P1 where 'an agreement of legal issues relates to BIM operation including approval and payment practice that must be agreed at the initial phase of commencement'.

Special Interest group (SIG)

Special interest group emphasised on a 'special group' of people forming a committee to provide a strategic direction and guidance on the development of local BIM standards and supporting resources (BCA 2011). It is highlighted by P5 that 'establishment of SIG could oversee the implementation of standards and addressing any issues that could impede the adoption of BIM'.

Research and Development (R&D)

Lastly, P2 and P3 indicated that 'R&D is an important element of innovation and the value of BIM implementation in R&D could be seen in collaboration between the industry and academia to produce BIM value for industry used'. It has been verified by Someya (1992), that technological development is rapidly changing and industry cannot remain competitive unless keep up with changing of technology by committing research and development. The idea corroborates with P6 that 'R&D priorities should be based on the current issue faced by the construction industry sector'.

Finally, the outcomes revealed that in term of Capacity elements; education and awareness; and R&D have not been addressed by the participants. The reasons could be the respondents are practitioners and not directly involved in education and R&D perspectives. In term of Support, once again the respondents failed to address standard and accreditation, SIG, and R&D. The reasons could be the respondents are unable to

appreciate on the development of standards and accreditation, formation of SIG, and development of R&D for the fact that these respondents have different interest in business needs. In term of Value, the respondent's failed to identify standards and accreditation, collaboration and incentives, education and awareness, BIM guidelines and legal issues, and SIG as the important elements for the development Malaysia's BIM roadmap. The reasons could be the respondents are yet to appreciate the outcomes and benefits of the related pillars. Despite, the outcomes are not fully supported by the respondents, the establishment of seven (7) pillars components are regarded as comprehensively developed by CIDB. The reason is that the government BIM-based pilot project was completed before the development of Malaysia's BIM roadmap. This predicament is unable to disregard the findings.

CONCLUSIONS

This paper is to establish the strategic analysis elements (i.e., capacity, support, and value) in the existing Malaysia BIM roadmap pillars based on the lesson learnt from Australia, Singapore and Hong Kong. Through a detailed analysis, seven significant pillars (i.e., standards and accreditation, collaboration and incentives education and awareness, national BIM library, BIM guidelines, SIG, R&D) were derived for the development of Malaysia's BIM roadmap. In order to enhance the existing roadmap, strategic analysis elements (i.e., capacity, support, and value) need to be embedded in the existing pillars. Through a formal workshop of expert panels, five out of seven pillars were incorporated as the capacity elements. These are: standards and accreditation, collaboration and incentives, national BIM library, BIM guidelines and legal issues, and SIG. In terms of support, four pillars were recorded incorporating support elements. These are: collaboration and incentives, education and awareness, national BIM library, and BIM guidelines and legal issues. The value for strategic elements however, is in another two pillars. These are: national BIM library, and R&D. By and large, all the strategic analysis elements (i.e., capacity, support, and value) should be embedded entirely in the seven pillars of Malaysia's BIM roadmap to ensure the implementation plan is comprehensive and viable as practised by Singapore in updating their BIM roadmap. As such the enforcement by the Government is inevitable to implement the Malaysia's BIM roadmap to be applied to all BIM-based projects. A continuous support within all parties involved is essential to drive the successful mission of BIM in Malaysia.

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THE IMPACT OF EMPLOYEE EXPERIENCE IN UPTAKE OF COMPANY COLLABORATIVE TOOL

Tamara Longwe¹, Wayne Lord and Patricia Carrillo

School of Civil and Building Engineering, Loughborough University, Leicestershire, UK

Working behaviours are not easily changed, even though technology has been put into place to improve employee productivity and performance. Although construction projects are completed by multidisciplinary teams, human input is a common feature which provides lesson learning beyond the confinement of discipline specific procedures. This research focuses on an SME Civil and Structural engineering consultancy which is in the process of adopting Building Information Modelling (BIM) within the context of the UK government 2016 mandate. This research will explore how organisations can capitalise on user experience to maintain continuity amidst technological and social changes. A qualitative research strategy was adopted, based on an extensive literature review and semi-structured interviews in order to provide a snapshot of the actions undertaken by organisations to profit from employee experience. Reliance on an employee's ability and experiences can be a bar as it limits an individual's willingness to adopt different and new ways of working. As such, experience is a double edged sword as past ways of working can act as an inhibitor to the adoption of new practices.

Keywords: adoption of document management, BIM, employee experience.

INTRODUCTION

Organisations in the construction industry are continuously being pushed to adapt and adopt new practices and processes to move away from the traditional approaches which encapsulate operations in the industry. Historically the construction industry has had a negative reputation with adopting new methods or processes despite legislative and competitive incentives. Practitioners within the industry still resist to readily adopting these new practices. Adoption barriers within the industry focus on three aspects; process; products; and people (Lindblad 2013). This paper will address this issue through an exploratory study of the impact of employee experience on the adoption of new practices within an organisation. The paper is focused on a civil and structural engineering consultancy in the UK which implemented "*Workspace*", a document management software programme which is supplied by Union Square. *Workspace* enables organisations to capture, store and retrieve documents as well as drawings, images and emails. The programme is on a web-based server and can only be accessed through a secure log-in on the internally hosted portal, with appropriate permissions given to users. The product exists in a default state, but it can be modified to suit the specific needs of the relevant organisation. The consultancy implemented *Workspace* two years ago as part of the plan to adopt BIM across the whole organisation.

¹ t.longwe@lboro.ac.uk

Document management is argued to be a central aspect of BIM (Gu and London 2010), this paper will adopt a hermeneutic stance and will refer to the findings from the implementation of “*Workspace*” to highlight what may be expected with the implementation of BIM. The paper focuses on the human aspect, specifically the impact of employee experience. It is widely accepted that a person’s understanding of something is shaped by their practical and observational experiences (Clough 1973). This paper is centred on both of these views since the skills and expertise that one has in a particular field, plays a part in how they observe, learn and complete tasks.

PEOPLE AND ORGANISATIONAL CULTURE

Culture in the context of an organisation has been described as, the collectively bound actions of individuals which hold an organisation together (Cheung *et al.* 2011). Researchers have placed great emphasis on the impact of culture on the internal and external operations of an organisation, culture is important because it influences the attitudes and behaviours which filter into decision making. Furthermore, other researchers have suggested that competitive advantage and operational effectiveness can be sustained by culture (Zheng *et al.* 2010; Walker 2011).

Despite the fact that processes and products can be managed stringently, there is great difficulty in managing people because of the additional unseen and intangible factors which are always at work. Human behavioural and emotional issues must always be factored in where a tangible understanding of how a person will adapt to new technology is sought (Henderson and Ruikar 2010). These factors vary between individuals, and the context in which they are applied but they necessarily influence rationality and an individual’s ability to perform tasks. Adequate managerial support is required to facilitate the adoption of new practices by employees. There are competitive advantages when technology is adopted but the process is always more comfortable when everybody within the organisation is aware and prepared for the anticipated change. However, the majority of writing comes from the perspective of senior and top management individuals i.e. those who drive implementation, instead of from those who actually use the technology on a daily basis. The adoption process as it stands is very under-inclusive and a different approach that engages more employees at different levels of the organisation is required (Arayici *et al.* 2011). This paper explores this from a wider research perspective

PAVING THE WAY FOR THE ADOPTION OF BIM

BIM provides an advent for the construction industry to improve the whole lifecycle of a project through technology, project team organisation and management principles. Adoption of new practices is an ongoing problem in the construction industry as there appears to be little scope within existing organizational frameworks to facilitate the adoption (Howard and Björk 2008). The paper focused on current progress of BIM adoption in the construction industry and argued that there is a discrepancy between current industry procedures and standards to enable the adoption of BIM to be effective. Froese (2010) subsequently argued (in the context of IT adoption) that current practice is not well suited for collaborative or integrated working and this acts as an impediment to effective adoption. However, recent research argues that the very nature of current construction projects lend themselves to new knowledge and require employees to implement novel ways of working (Bygballe and Ingemansson 2014). Theories have been developed and adopted within the construction industry to facilitate successful adoption such as Technology Acceptance Model (TAM). However these claims appear to be unfounded, if the

industry was well suited for new ways of working, then surely there would not still be problems with adopting new practices.

Another argument placed emphasis on the actual complexity of the BIM solutions lending themselves for adoption to initially focus on limited areas (Howard and Björk 2008). A contrasting argument stated that there are more reasons against the implementation of BIM than there are for its implementation (Ashcraft 2008). Due to the apparent complexity of BIM solutions and the organisational changes required, individuals are further deterred from adopting new practices despite the evident benefits which could be achieved. This further shows the impact which an individual's experience can have on the adoption of new practices as a lack of understanding is a key hindrance to the adoption of new practices (Alshawi *et al.* 2010).

Technology Acceptance Model

Organisations have been advised to initially consider installing the technology with the lowest probable barrier to adoption (Davis and Songer 2008; Xiao and Noble 2014). This approach of implementing specifically selected components of technology to maximise the adoption success rate was argued in the context of the Technology Acceptance Model (TAM) theory Davies and Harty (2013a). TAM is widely accepted, used and tested in research to help understand and explain user behaviours in Information Systems (Venkatesh and Bala 2008; Legris *et al.* 2003) and technology (Straub *et al.* 1997; Straub 2009). TAM aims to resolve the ineffectiveness of attempts to adopt new technology that may be a result of individual experiences acting against these adoption attempts. The model focuses on an individual's belief on the perceived usefulness of technology to increase their job performance.

The application of TAM was most applicable for the project as it will provide an understanding of the individual beliefs that each employee has towards technology adoption and what lessons can be learned for the future. Additionally Davies and Harty (2013b) used TAM when focusing on the decision making and implementation of electronic document management, electronic data exchange and BIM. The authors focused on an individual's level of acceptance and parameters were established to measure individual beliefs for technology acceptance and use; these were as follows:

Performance expectancy: 'the degree to which an individual believes that using the system will help him or her to attain gains in job performance';

Effort expectancy: 'the degree of ease of use associated with the system';

Social influence: 'the degree to which an individual perceives that important others believe he or she should use the new system';

Facilitating conditions: 'the degree to which an individual believes that an organizational and technical infrastructure exists to support use of the system'; and

Attitude: toward using technology, an individual's overall affective reaction to using a system.

Furthermore the practicality of TAM theory in this research is grounded on establishing lessons learned from the adoption of *Workspace* to guide the adoption of BIM. TAM theory was used to conduct a comparative analysis of *Workspace* adoption. A key aspect of TAM requires employees to be aware of all the specifics (what will be changed and how it will be changed) of the intended change (Davis and

Songer 2008), also required for this research. Despite widespread acceptance that TAM theory can be utilised to facilitate adoption, one major critique is its lack of guidance to assist in its application (Lee *et al.* 2003), this is therefore an area to address.

Adopting new technology

Adopting new technology is a way for organizations to adapt to new situations (Alshawi, Lou and Goulding 2010), this has positive competitive benefits for the organisation within its operating market. The authors focused on organisational soft issues which influence the implementation of information systems and information technology in organisations. The main conclusion was that the construction industry still has to overcome barriers which inhibit the adoption of IT. However, the authors did not identify what the barriers which hinder the adoption of IT in the construction industry. Nonetheless, it provided an insight into the ripple effect that the adoption of new technology has. This related to changes to the organizational structure and culture.

Henderson and Ruikar (2010) conducted research on factors which influence successful adoption of technology by construction industry companies. One of their findings suggested that poor uptake of technology is a result of the disparity of experiences between large and small sized companies. This implies due to the significantly large quantity of “*small*” companies operating within the industry the success rate has been negatively skewed. This is well understood in terms of measurements such as the number of employees and annual turnover. The next section will discuss the research methods adopted in order to provide conclusions based on meaningful inferences. Data will be collected using semi-structured interviews for a more in depth discussion of the problems identified in the literature review.

RESEARCH METHODS

A qualitative research strategy was adopted for this project. The use of qualitative research enables data to be collected whereby respondents can convey and express their views. Quantitative research methods were deemed unsuitable because the research project isn't focused on statistical findings of the impact employee experience has on adoption practices within an organisation. The focus is on the exploration of the reasons why employee experience impacts adoption practices and what lessons can be learned to inform future adoption projects. Naoum (2012) stated qualitative research emphasises meanings, experiences and provides description. Bryman (1992) also stated that qualitative research enables opinions, views and perceptions to be gathered. This has been used in research to understand beliefs, opinions, views and perceptions regarding factors affecting the industry in the application of new technology (Howard and Björk 2008). Although quantitative data can provide meaning inferences, these are subject to the interpretation of the researcher which may be affected by bias in comparison to qualitative data which is based on intrinsic explanations of an individual.

Data collection

The literature review identified themes which affect or are affected by employee experiences in adopting new practices. The questions were developed to resolve gaps identified but also validate the findings in literature in relation to the research aim. The summarised responses were reviewed in conjunction with the findings in the literature. Semi-structured interviews were conducted, as the nature of this

interviewing technique enables the respondents to explore and discuss other themes that may not have been apparent in literature. The interview questions were categorised to build a detailed profile of each respondent (work history, experience, expertise) and also enable reflection of each section before proceeding to the next question. This form of data collection enabled the researcher to define who the respondents were; determine the required sample size in relation to the use and the relevancy of the results.

Population sample

The respondents for the interviews were employees of a civil and structural engineering consultancy based in the Derby (UK) head office, operating in the departments that undertake project work in the building environment (structural, civil engineering and environmental). The company has an annual turnover of £5million and a workforce of over sixty employees across three offices; fifty of the employees are based in Derby. The organisational chart for the organisation was reviewed and at least two respondents were selected randomly from each department to represent the different roles which ranged from technicians to project engineers and directors. All the respondents were required to have had at least six months experience within the organisation, so that they should have had practical experience in the *Workspace*.

FINDINGS

Workspace provides a central repository for storing all project data through a formal convention. Wider accessibility of information contained within emails was the main driving force in the organisation adopting the *Workspace* software. As with any software the success of *Workspace* is reliant on how individuals implement it, and based on actual findings from data collected so far it has been used inconsistently by individuals across all the different management levels and departments. The analysis of the findings will be based on the criteria established by Davies and Harty (2013b) as it considers an individual's level of acceptance.

Table 8: List of interviewees

Code	Job role	Department	Management level	Years in Company	Years in industry
A	Director	Environmental	Director	12	19
B	Project Engineer	Environmental	Middle	8months	8
C	Senior Technician	Structural	Senior	13	34
D	Senior Project Engineer	Structural	Senior	9	9
E	Divisional director	Civil	Director	14	14

Interviews were conducted with five respondents occupying the roles of; technician, project engineer and director in their respective department as shown in *Table 1*. Each interview lasted no longer than an hour, and the interview questions covered the themes of; culture, context, legislation, standards, and collaboration. The use of semi-structured interviews allowed the respondents to provide insight into other themes which affect the adoption of new technology such as training, operational performance and other such relevant issues.

Performance expectancy

The interviewees unanimously agreed that *Workspace* is a good tool for managing emails but not so good for the management of project specific data, i.e. saving

drawings in X-ref format has been a problem. *Workspace* isn't particularly useful as a working tool and is seen as archive storage (Respondent A). Although all employees understood that everything has to be stored on *Workspace*, not everyone is doing this. It has been highlighted that limited organisational support negatively affects BIM adoption (Xiao and Noble 2014). The responses that were provided indicate that the adoption of *Workspace* has not been supported by the whole organisation, as employees are failing to fully utilise *Workspace* fully because of their individual experience and lack of thorough understanding of *Workspace*'s facilities. It can be argued that a similarities situation can be expected to the possible adoption of BIM. This is because negative perceptions which limits the adoption of BIM can be attributed to a lack of understanding and awareness to the benefits and capabilities of BIM solutions (Gu and London 2010). Respondent E reinforced this by stating there is a general lack of awareness of the specific capabilities of *Workspace*. It is evident that if employees were made fully aware of the benefits and capabilities of *Workspace* this would facilitate its successful adoption. *Workspace* can be used to draw parallels of what is to be expected with the implementation of BIM because document management is an integral part of both systems (Davies and Harty 2013a; Gu and London 2010).

Effort expectancy

Workspace was expected to provide a central location to store all project data but it has not been particularly successful in changing old working habits as attitudes are much harder to change. Respondent A stated that *Workspace* requires discipline, which tends to vary between people, whilst respondent B stated that getting into the habit of using *Workspace* properly is the difficult part to grasp, this was from a Director and middle management perspective. Both arguments support that people's behavioural patterns are not easily changed. BIM adoption requires a change in mindset and work processes not just by single actors or individuals but as a collaborative effort (Lindblad 2013). *Workspace* was implemented for adoption across the whole organisational structure and requires all employees to implement it correctly. The weakness and failure of *Workspace* to support certain drawing formats such as X-ref has resulted in employees maintaining use of the "*P-drive*" on the IT network as experience has proven the success of that method (respondents C and D). This resistance to adopting *Workspace* is due to experience and could possibly occur with BIM, as there are some fundamental principles which employees could choose to ignore such as information management or collaboration because of their experience and their previous ability to complete work successfully.

Social influence

The success that result from innovative change, can only be fully realised if they are influenced and supported by constituent members of the organisation (Alshawi *et al.* 2010). A top-down approach was adopted for the implementation of *Workspace* with senior management spearheading and promoting its implementation throughout the organisation. It appears from the interviewees own subjective view, that they were not under pressure to conform with the use of *Workspace* when it could not support their requirements. Respondent D stated that personalities play a big part in the application of technology because some people are good, and others are bad at adopting new ways of working Measures that are put into place to facilitate the adoption of new practices however, are indiscriminate between individuals (Gu *et al.* 2007).

Facilitating conditions:

The measures that are taken prior to the instigation of change are just as important as those that are taken during and after the implementation (Xiao and Noble 2014). Respondent E (a director) acknowledged that more could be done to ensure that employees were provided with the appropriate training to enable the effective usage of *Workspace* and respondent A (a director) further argued that a degree of IT literacy is required in addition to the training provided. Respondent A additionally stated that strict and disciplined application of *Workspace* is an area that the organisation has to improve at a cultural, individual, team and business level. Furthermore, discussions which emphasize the need for technology on an organizational level (Alshawi *et al.* 2010) and redirection of technology adoption problems as an impersonal issue further fuel this need.

Attitude

The process for the adoption of technology has to be inclusive in order to avoid slow adoption and resistance (Arayici *et al.* 2011). Respondent D highlighted that resistance to the adoption of new technology should be expected “*because you spend over 10 years doing things one way and suddenly changing to another*”. This statement supports the necessity of the adoption process being incremental and focusing on limited areas (Howard and Björk 2008) to avoid sudden changes which can be very disruptive to working momentum. Past experience undermines adoption regardless of how effective a new practice or technology will be, and those lower down the organisational hierarchy are more likely to resist adoption than others (Henderson and Ruikar 2010). This was evident in the interview responses; the Directors (A and E) showed the least amount of resistance to adopting *Workspace* as compared to the other respondents. Respondent B expressed that using *Workspace* as is required would be a time consuming exercise, but concluded by saying that realistically, the time spent is no different to that on existing methods of storing data. This re-enforces the argument that perceptions with regards to the expected use of technology actually affect its use (Straub 2009).

CONCLUSIONS

The findings of this exploratory research have illustrated the impact employee experience has had on *Workspace*, and as such what may be expected when BIM is implemented. Based on the reception of *Workspace* within the organisation, it is vital for the implementation of BIM that negative attitudes towards its adoption be quelled and positive attitudes nurtured and encouraged in order to facilitate effective adoption. To overcome resistance, measures need to be employed in the form of; active participation, training, communication and education. In particular, it is fundamental that these measures are not only present during and after implementation, but also at the pre-initial stage any of any change.

One limitation of this work is that this paper comes from the perspective of a consultant and its employees. It does not consider the point of view of the project manager or the other project stakeholders i.e. the clients, system developers and others. Indeed the findings of the research will be beneficial to the organisation primarily but it would be invaluable to acquire data from other disciplines that have implemented document management on their journey to adopting BIM.

There are numerous benefits to using *Workspace* as a collaborative tool, but these cannot be realised unless it is used correctly and universally. Moving forward, it

would be useful to appoint a user champion within each department to encourage the adoption of *Workspace*, ahead of the BIM implementation. A similar BIM champion would make it possible for any issues that arise to be dealt with directly. Finally, making the review of *Workspace* usage an agenda item in the annual performance reviews, would emphasise the importance of feedback and the vital role it plays to improving the work environment.

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BIM ADOPTION IN INTEGRATED SUPPLY CHAINS: A MULTIPLE CASE STUDY

Eleni Papadonikolaki¹, Ruben Vrijhoef and Hans Wamelink

Faculty of Architecture and the Built Environment, Delft University of Technology, Delft, The Netherlands

This paper explored the status of BIM adoption in construction Supply Chains (SC). The benefits of BIM are found from design management, to virtual construction and site management. The study is structured upon the assumption that BIM not only supports intra-firm collaboration, but also improves inter-firm collaboration in projects with SC management (SCM) application. Next, a set of real-world SCM projects was analysed empirically via interviews and questionnaires. These BIM-based SCM projects displayed various degrees of SC team integration and BIM collaboration routines. The multi-case analysis suggested that BIM-readiness was a significant parameter for choosing partners and forming the SC partnership. Finally, the paper compared various levels of BIM collaboration to SC maturity and discussed the benefits and lessons learned from combining BIM technology and SCM theory.

Keywords: building information modelling (BIM), supply chain management (SCM), BIM-based collaboration, integration.

INTRODUCTION

The use of Building Information Modelling (BIM) becomes the norm in Architecture, Engineering and Construction (AEC). Numerous different professionals apply BIM in different phases. Undoubtedly, BIM offers many benefits in AEC projects, such as time reduction, communication and coordination improvement, lower costs and fewer returns for information (Azhar, 2012, Bryde *et al.*, 2013). Yet, there is an abundant rhetoric on BIM's collaboration benefits (Barlish and Sullivan, 2012, Mondrup *et al.*, 2012), but without examining the impact of BIM in already integrated multi-disciplinary teams above organisational barriers, e.g. Supply Chain (SC) partnerships.

Supply Chain Management (SCM) manages the flows of material, information, and cash, by encouraging close project-based collaboration and engagement to future collaborations within strategic partnerships. This close relation among different professionals implies sharing both rewards (e.g. fewer economic uncertainties) and risks (Vrijhoef, 2011, Vrijhoef and Koskela, 2000). On one hand, SCM underperforms when it merely adopts the traditional workflows, due to lack or redundancy of information. On the other hand, BIM offers an integrative technology for information sharing among extended teams. However, the changes from BIM-enabled SCM and the exact BIM-enabled collaboration process are not yet adequately researched.

The combination of BIM technology and SCM practices is understudied. There is significant research on BIM collaboration for extended project-based teams (Cidik *et*

¹ E.Papadonikolaki@tudelft.nl

al., 2010, Van Berlo *et al.*, 2012), but not for already structured, trusting and long-term SC partnerships. This paper describes BIM use within such SC partnerships. It reveals the changes in the SC team roles and investigates the practical issues of BIM use in its full potential (multi-stakeholder use) within the SC. This study reports on BIM adoption in five real-world SCM projects by analysing the engagement to BIM and SCM and concludes that nowadays a BIM-enabled routine can greatly promote SCM. Likewise, BIM collaboration process is greatly enriched by SCM practices.

This paper performed a multiple case study research to analyse the changes induced in SCM settings by BIM adoption and to describe the actual BIM use within such multi-disciplinary teams. The rest of the paper contains the background and presents the methodological framework. Subsequently, the paper presents the findings and with the discussion section, it concludes with the status quo of BIM use in SC partnerships and a set of suggestions for effective BIM-enabled SCM application.

RESEARCH BACKGROUND AND GAP

The recent research on BIM adoption in AEC suggests that project complexity raises from the involvement of an increased number of interacting project actors (Hickethier *et al.*, 2013, Zavadskas *et al.*, 2010). Moreover, a recurring issue in the literature has been the need to inspire and retain trust during the multi-disciplinary collaboration with BIM (Cao *et al.*, 2015, Miettinen and Paavola, 2014). Yet, in practice, the distributed relations among the SC actors that are engaged in SCM practices already present trust and openness. By consciously aligning a firm's operations to that of a federation of SC partners, the relations transform from distrustful to transparent. Thus, SCM offers a fertile ground for trust in BIM-based collaboration.

SCM regulates the material, information and cash flows among a set of aligned companies. Previous research has underlined that BIM is fully capable of supporting these flows. One, BIM regulates the material flows through BIM-based monitoring methods (Irizarry *et al.*, 2013). Two, BIM has positively changed the cost estimating processes by providing ground for reliable estimations (Forgues *et al.*, 2012, Hartmann *et al.*, 2012). Three, BIM effectively manages the information flows, since it is a structured data model of building information per se. Thus, BIM supports SCM by offering a set of options for managing the material and cash SC flows and various methods for the rationalisation and standardisation of the information flow.

As described above, it is evident that BIM technology and SCM theory can mutually support one another when they are simultaneously applied in projects. After all, the SC partner selection process has transformed from price-based criteria to more soft criteria, such as quality of collaboration (Pala *et al.*, 2014, Sporrang and Kadefors, 2014) or their ability to use ICT, e.g. BIM, as an interface (Mahamadu *et al.*, 2014, Yin *et al.*, 2014). Thus, we hypothesise that BIM transforms the roles and SC partner relations in SCM. Also, practical issues have emerged during BIM adoption in multi-disciplinary teams (Van Berlo *et al.*, 2012, Cidik *et al.*, 2010), which suggests that BIM research takes the distributed character of SCM, under consideration.

In the traditional SC research the general contractor, who has been usually considered the “*focal*” firm, together with sub-contractors and often some suppliers form the SC. Today, many more different specialties are actively involved in the SC partnership and the theory of “*focal*” firms has shifted towards a more distributed and complex system. BIM requires the active involvement of various other professionals, (apart from the traditional SC) such as clients, asset owners and design firms (Love *et al.*,

2014, Son *et al.*, 2015). This paper addressed organisational and collaboration aspects of BIM by exploring and proposing SCM as a solution. It explored two main research questions and filled the respective gaps with empirical data:

- 1-What are the changes in the roles of the SC actors from BIM-enabled SCM?
- 2-How is BIM-based collaboration currently applied within SCM practices?

METHODOLOGY

The research is based on a case study research design. The case studies were selected for exploring the combination of SCM theory and BIM in practice by providing a “*real-life context*” to the hypothesis (Yin, 2003). To offer a pragmatic overview, the case results were later compared to the literature, to strengthen the existing research or detect any discrepancies. To ensure the reliability and generalisation of the study, strategies for a diverse sample of representative BIM-based SCM projects were used.

The case study included a sample of representative projects, selected from a set of email communications carried out during the last quarter of 2014 towards 52 Dutch construction practitioners who engage in SCM. These professionals have diverse roles, e.g. investors, contractors, architects and consultants. Totally, 29 different AEC firms were initially contacted. Next, 14 SCM projects with BIM adoption were evaluated for use in this study, as to timing and availability. This sample was further reviewed to identify cases that fulfilled the following selection criteria with diversity:

- Type: Building construction: multifunctional (MF), housing or utility.
- Scale: Small (up to 2,000 sqm) to large (more than 20,000 sqm) projects.
- Team: A multi-disciplinary SC partnership that is composed from at least a design team, a contractor and a client/owner organisation.
- History: The partnership has been active for at least one other project.
- Vision: The partnership expresses a clear vision for future collaboration.
- Technology: Use of BIM-based tools from at least one SC partner.

From the 14 projects, five cases were shortlisted for further exploration, since they complied with the selection criteria, fit an appropriate research timeframe and offered the desired diversity. In all cases, the contractors were the initiators of BIM adoption and SCM practices. All projects were studied between Definitive Design and construction Preparation, during the first half of 2015. For confidentiality the selected SCM projects are mentioned as A, B, C, D and E (sorted in chronological order of recruitment). Table 1 shows an overview of these five selected SCM cases:

Table 1: Compliance and variety of the BIM-based SCM projects to the case selection criteria.

	Type	Scale	End date	SCM use	History	Vision	BIM use	Extent
A	MF	Large (L)	02/2016	Yes	2 projects	Unclear	Yes	Local
B	Housing	L	12/2015	Yes	All projects	Yes	Yes	National
C	Utility	Mid-(M)	10/2015	Yes	All projects	Unclear	Yes	National
D	Utility	Small (S)	10/2015	Yes	All projects	Yes	Yes	National
E	Housing	M	08/2015	Yes	3 projects	Yes	Yes	Local

Seuring *et al.* (2005) claim that case study is among the standard research methods for SC research. Since a SC is a distributed system, an equally distributed method of data collection from interviews and questionnaires was used to maximise the exploration of the topic. The selected case study design shifted away from the traditional research on the “*focal*” firm of the SC and devoted about equal time to all SC partners (from top

management to modellers). The projects were periodically and discretely followed and in total five chains with 44 professionals from 31 different firms were interviewed.

The data collection method (interviews and questionnaires) was first tested in a pilot case study during the first quarter of 2014 and later amended to assure question validity and compliance to research goals. Semi-structured interviews with all SC actors (5-10 actors per project) were used. There were three data collection phases:

- Phase 1: SCM analysis: Questions about the strategy, history, vision and application areas of the SC addressed to the top management (internal SC);
- Phase 2: BIM analysis: Questions on BIM adoption and BIM application areas addressed to the whole SC (including the external SC partners);
- Phase 3: BIM analysis: Attended “*BIM meetings*” among the whole SC.

Since the five projects are currently ongoing, the paper analyses only their SCM and BIM aspirations and their collaboration routine during the initial stages. The authors retain reservations as to the final outcomes of the projects, since for some, BIM is a recent entry and their collaboration routine may be revised. The selected methodology provided an overview of the SC status, goals and BIM use in BIM-based SCM cases. Afterwards, the cases will be followed for a total period of maximum 1.5 years, depending on the scale, to detect the full impact of BIM-enabled SCM practices.

SCM DESCRIPTION AND ANALYSIS – PHASE 1

The studied projects had various SC team compositions spread along the different project phases. The partners varied per project based on the technical requirements and investment ambitions of the SC. In all projects, the contractor was internal member of the SC. The rest of internal SC members were found in both the forward SC part (from initiation to design), e.g. clients and designers and the backward SC part (from construction to operation), e.g. installation firms and suppliers. The rest of the involved actors (apart from the contractors) per project are as follows:

- Project A: The structural engineer, energy advisor, heating, energy and plumbing firms and facility manager were internal SC members.
- Projects B, C and D: The architect, structural engineer, steel sub-contractor and few suppliers (e.g. windows, roof) were internal SC members.
- Project E: The structural engineer, heating engineering and installation firm and client and facility manager were internal SC members.

As regards the project stages with SCM application, there were various configurations according to the project history and underlying SC strategy. In particular, SCM was applied in the following stages of the projects:

- Project A: SCM was applied from Preliminary Design until Operation phase. The project was initiated as Design-Bid-Build.
- Projects B and D: SCM was applied from Initiation until Operation.
- Projects C and E: SCM was applied from Schematic Design until Construction phase. No plans were made for Operation and Maintenance.

A diverse sample of BIM-based SCM projects was collected. Table 2 illustrates the levels of SCM maturity. The first column to the left contains the project identifiers (A, B, C, D and E). The columns include SCM maturity factors adapted from Vrijhoef (2011). The cells contain the descriptions “*Yes*” and “*No*” when a particular SCM application area is or is not present in the case, respectively. The last column to the right relates the overall SCM maturity according to the total number of factors present

in each case (data in the column on the left of the last) with Ad hoc, Defined, Linked, Integrated or Extended types, adapted from Lockamy III and McCormack (2004).

Table 2: Factors of SCM applications per case (column list adapted from Vrijhoef (2011)).

	Integration of business activities	Partner sourcing	Integration of operations	Logistics control	Quality management	Information exchange	Product design & development	Market approach and marketing	Cultural alignment	Human resource management	Total number of present factors	Overall degree of integration
A	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	8/10	Linked
B	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	8/10	Integrated
C	Yes	Yes	No	Yes	No	Yes	No	Yes	Yes	No	6/10	Linked
D	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	8/10	Integrated
E	No	Yes	No	Yes	No	Yes	Yes	No	No	No	4/10	Defined

BIM DESCRIPTION AND ANALYSIS – PHASES 2 AND 3

BIM adoption in BIM-enabled SCM practices

BIM was adopted with various nuances throughout this study. BIM was used in the Preliminary Design (PD), Definitive Design (DD) and Technical Design (TD) phases for every SCM project. At times, BIM was used in construction (projects A, B and D), while BIM-based operation was allegedly doable in some SCM projects (A, B and D).

BIM has various applications in AEC according to Cao *et al.* (2014). Yet, BIM was used in only a few of the acclaimed application areas in the studied projects. Table 3 presents an overview of these applications per case. The first column to the left contains the project identifier. The table cells contain the descriptions “Yes” and “No” when a particular BIM application did or did not take place, respectively, in the project. Overall, most applications of BIM were found in: 3D representations, design coordination, clash detection and quantity take-off. Rarely, they used BIM for cost estimation, energy simulation and site management. The last column indicates the equivalent BIM maturity level, according to UK National standards (GCCG, 2011).

Table 3: BIM application areas per SCM project (column list adapted from Cao *et al.* (2014)).

	Site analysis	Design exploration	3D representation	Design coordination	Cost estimation	Energy simulation	Clash detection	Construction system design	Schedule simulation	Quantity take-off	Site resource management	Offsite fabrication	UK BIM maturity
A	No	No	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	Level 3
B	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	No	No	Level 3
C	No	No	Yes	Yes	Yes	No	Yes	No	No	Yes	No	No	Level 2
D	No	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	No	No	Level 3
E	No	No	Yes	Yes	No	No	Yes	No	No	Yes	No	No	Level 2

Actual SC collaboration via BIM

After attending their “BIM and Design” meetings, the five SCM projects were found to display three levels of BIM-based collaboration. These were encoded as *ad hoc*, *linear* and *central*. The next paragraphs present them in increasing order of integration by describing their characteristics per project that displayed them.

Ad hoc BIM collaboration was observed in project E. Only some SC actors used BIM and the contractor was responsible for coordinating their BIM models occasionally by exchanging proprietary BIM models. Also, the exchange of traditional means such as prints of 2D drawings, frequently and iteratively, was greatly encouraged.

Linear BIM collaboration process was observed in projects B, C and D. Most actors used BIM, apart from some suppliers. The BIM collaboration took place by merging segregate models to one with model checker software, via IFC. Yet, the collaboration was linear, since the contractor (who was in charge of model merging) had individual and on-demand BIM sessions with each SC partner and informed the rest by email.

Central BIM collaboration process was observed in case A. The contractor was responsible for merging segregate models weekly with model checker software. The coordination of their activities was achieved by hosting regular joint BIM meetings fortnightly. The client organisation (albeit not an internal SC member) also attended the sessions to stay updated and ensure their needs were met.

INTERPRETATION OF THE OBSERVATIONS

Impact of BIM on SCM practices

BIM adoption has irreversibly changed the relations and organisational structures not only to one firm, but also to the whole SC. The 42% of firms (13 firms) who took part in the study claimed that adopting BIM was an internal decision (often taken in 2000) to serve their intra-organisational needs for advanced ICT. Most firms adopted BIM during 2005-2008. The rest interviewed firms (58%) claimed that BIM adoption was an external but natural decision, since they had to meet client and market demands.

BIM skills are often a criterion for partner selection when forming the SC. In case E, they performed an unofficial competition (with brief and presentation) among their past preferred partners to select the most BIM-savvy partner. In cases B and D, process quality, which entailed BIM use, was superior than price, for partner selection.

In the study, the BIM-using firms also used it in about half of their projects, included it into their business plans and advertised their BIM-readiness. Yet, since their BIM project portfolios contained 1-4 projects, there were various levels of BIM skills in the SCs. In decreasing order of BIM experience, the SC of project E had two past BIM-based projects, A had one and B, C, D had sporadic BIM applications respectively. Thus, the BIM-readiness of the SC further relied on the BIM-readiness of the partners.

Impact of SCM on BIM practices

BIM changes the collaboration within SCM practices. The partnerships were retained and supported, even if non-BIM using partners participated. This held true in all cases. The outliers either followed a traditional process or were learning on-the-job. The BIM-using partners of cases A and E helped the less experienced partners during extra sessions. In the rest, the BIM challenges were solved informally and on-demand.

Written regulatory agreements are popular within SCM practices. The studied cases used customized BIM protocols based on BIM norms issued by the Dutch Building Agency. The SC partners used such BIM protocols to define their BIM process aside the existing SC contracts, which defined their obligations and rewards. The cases A, B and D customised the BIM norms to their particular traits and needs. These protocols included a description of their particular BIM goals, modelling stages, Level of Detail (LoD), timelines, deliverables and directions for their physical interactions. Thus, their BIM collaboration was enriched by contractual means also present in SCM practices.

Apart from written agreements, the SCM practices influenced the physical BIM collaboration. In cases A, B and D one or more joint meetings with all partners were held, i.e. *BIM meetings*, *BIM Design and Engineering meetings* or *BIM Design sessions*. These meetings resembled a lot to pull-planning sessions (which were also

included in cases B, C and D) as to the established underlying trust and pursuit of mutual gains and understanding. Their periodicity, duration and any special sessions were set in the BIM protocols. The BIM meetings were usually obligatory for all – so as to share their information –, held weekly or fortnightly and lasted about two hours. The contractor of case A hosted further regular, weekly and optional “*BIM sessions*” for calibration.

Cumulative impact of BIM-enabled SCM practices

The explored cases offered insights into the adoption of BIM-enabled SCM. Table 4 summarises the previous observations. The first column to the left contains the case identifiers. The next shows data on project type and scale. An analysis of BIM use as to the actors, applications and collaboration is shown afterwards. The next three columns show SCM adoption as to the actors, applications and maturity. A mismatch was noted between the level of BIM collaboration and SCM maturity. Case A featured advanced BIM-based collaboration, even if the SC was young and vice versa: mature chains used BIM without utilising its full potential (e.g. B, D). The last column to the right contains an estimate based on these mismatches. *Central* BIM collaboration and *integrated* SCM practices are both elements of *promising* practices, even if BIM and SCM use was *linear* and *linked* respectively (e.g. A, B, D). Case C was deemed *unclear* due to existing risks that did not allow for integrated operations (Table 2). Case E was considered *poor* example of BIM-enabled SCM, as *ad hoc* collaboration could support neither integrated building information nor further SC integration.

Table 4: Findings of the analysis of the selected projects with BIM-enabled SCM practices.

Description (Type and scale)	Actors using BIM	BIM application areas	BIM collaboration process	Actors of SCM	SCM application areas	SCM maturity	BIM & SCM overview
A MF; L	9/10	7/12	Central	7/10	8/10	Linked	Promising
B Housing; L	9/11	7/12	Linear	9/11	8/10	Integrated	Promising
C Utility; M	5/8	5/12	Linear	5/8	6/10	Linked	Unclear
D Utility; S	5/9	6/12	Linear	5/9	8/10	Integrated	Promising
E Housing; M	6/8	4/12	Ad hoc	4/8	4/10	Defined	Poor

These case studies are ongoing and the authors refrain from generalising. The study goal was to explore the current status of BIM and SCM combination in industry. One study limitation is that for proximity, all projects were based on the Netherlands. Yet, useful lessons could be extracted for other countries as well.

DISCUSSION

Changes in the SC relations from BIM adoption

The traditional SC was formed by the interplay of price and trust (Segerstedt *et al.*, 2010). The contemporary SC is formed not only as to price, delivery or quality, but also as to their BIM-readiness. In cases A, B, E, the firms sought equally BIM-skilled SC partners, perceiving BIM as a unique selling proposition. The contractor and client were dedicated BIM-aspirers, apart from drivers of SC integration (Ling *et al.*, 2014).

The numbers of involved stakeholders in a project constantly increase (Zavadskas *et al.*, 2010) and simultaneously their existing roles change. Their relations transform from adversarial to symbiotic in the light of achieving the reported benefits from BIM adoption (Azhar, 2012, Barlish and Sullivan, 2012, Bryde *et al.*, 2013, Hartmann *et al.*, 2012). The following list includes the new and amended roles (from BIM-enabled SCM adoption) of the most influential actors as seen throughout the five SCM cases:

- The client aligned to the market demands and requested BIM-enabled project delivery but rarely had a strategy for using BIM during operation.
- The contractor was the BIM-integrator, used it for audit and often offered the basic infrastructure (physical and digital) for BIM-based collaboration.
- The design and engineering team was the BIM forerunner. All architects and structural engineers were BIM-proficient in the studied projects.
- The sub-contractors were tech-savvy and efficient with BIM, since most of them were familiar with building product models before the debut of BIM.
- The suppliers were starting to adapt very competitively in the BIM process.

Advantages and limitations from combining BIM and SCM

Azhar (2012) claims that early engagement with BIM is doable, yet in the study it was mostly used in design and construction. This “late” adoption could be related either to the usually less BIM-proficient project initiators (e.g. client, user), or the fragmented AEC lifecycle just before the permission stage (e.g. project A) that allowed for delays.

The BIM collaboration in SCM projects was achieved through aggregate reference models. The collaboration was mostly supported by other types of interaction, e.g. physical meetings, since it is in fact asynchronous, as Cerovsek notices (2011). The BIM protocol assisted the definitions of “what” to exchange, LoD and modelling stages. The SCM practices, shared history and experiences among the SC actors enriched the definitions of “how” and “when” to interact, e.g. issuing specifications and hosting regular and special physical meetings. The intuitive SCM practices also promoted co-design and the emergence of shared BIM vision via team collocation (cases B, C, D). The main BIM benefit for SCM was the continuous information flow and the main SCM benefit for BIM adoption was the collaboration in a trustful setting.

Despite the benefits from BIM-enabled SCM, some challenges were reported. The actors of the projects A, B, C and D required denser interactions from time to time. Another recurring issue was the ownership of design in certain design tasks. They repeatedly asked: “Who draws what?”. The collocation, which was encouraged by the SCM practices, perfectly resolved such doubts. Therefore, BIM and SCM practices complemented each another and gradually overlapped. Yet, the younger chains were more BIM-savvy and vice versa; the mature chains displayed a rudimentary BIM-based collaboration routine and they relied more on their SCM relations: common experience, shared background, expertise and familiarity. To devise an evaluation of the various BIM-enabled SCM configurations; *promising*, *poor* and *unclear* descriptions were given (Table 4). An additional hypothesis is that *integrated* SCM practices could support a *central* BIM-based collaboration in the future.

The discovered BIM collaboration patterns— *ad hoc*, *linear*, and *central* – might also be applicable to non-SCM settings. The recruitment of these BIM-enabled SCM projects was facilitated by the already organised SC actors in partnerships and their collective decision to share information for research purposes. After all, the promise of BIM for integral information aligns to the need of SCM for regulated information.

CONCLUSION

This study investigated the influence of BIM upon forming and supporting SCM practices in AEC. First, it identified that BIM-proficiency was important aspect of partner selection. Moreover, the level of the actors’ BIM-proficiency shaped the type of BIM-enabled SCM collaboration processes. The BIM-enabled SCM routine included written agreements and frequent physical interaction that greatly resembled

SCM contracts and joint sessions respectively. Second, the paper identified ad hoc, *linear* and *central* BIM collaboration processes. Using BIM with *central* collaboration from design until operation was the most promising and smooth route to reach the full potential of SCM practices. Yet, a *linear* collaboration process sufficiently supported small and simple projects when combined with integrated and mature SCM.

A diverse sample of Dutch SCM projects was explored and it was concluded that SCM theory is fully supported by BIM, which in turn provided the mature SCM configurations with integration of information flows. Simultaneously, BIM adoption was enriched by SCM theory so as to perform in its full potential, as described above. Yet, there was a mismatch between the extent of BIM collaboration and SCM maturity, which could be improved by more frequent interactions and peer BIM trainings. Overall, BIM was used as an inclusive design and information platform, but had not yet reached its full socio-technical maturity, which could be activated and supported by applying it in teams with already achieved trust, i.e. SCM environments.

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INVESTIGATING THE DIFFUSION OF 4D BIM INNOVATION

Barry Gledson¹

Department of Mechanical and Construction Engineering, Northumbria University, Northumberland, UK

UK Government regularly applies challenging strategic targets to the construction industry, chief amongst these are requirements for more rapid project delivery processes and consistent improvements to the time predictability aspects of on-site construction delivery periods. Latest industry KPI data has revealed a recent increase across measures of time predictability, however more than half of UK construction projects continue to exceed agreed time schedules. The aim of this research was to investigate the diffusion of 4D BIM innovation as adoption of this innovation is seen as a potential solution in response to these targets of construction time predictability. Through purposive sampling, a quantitative survey was undertaken using an online questionnaire that measured 4D BIM innovation adoption using accepted diffusion research methods. These included an exploration of several perceived attributes including compatibility, complexity, observability and the relative advantages of 4D BIM innovation in comparison against conventional functions of construction planning and against stages of the construction planning processes. Descriptive and inferential analysis of the data addresses how the benefits are being realised and explore reasons for adoption or rejection decisions of this innovation. Results indicate an increasing rate of 4D BIM innovation adoption and reveal the typical time lag between awareness and first use.

Keywords: 4D planning, building information modelling (BIM), construction planning, innovation diffusion.

INTRODUCTION

Emphasis on the time performance of UK construction industry was documented in a 2013 governmental strategy report (HM Government, 2013) where a ‘Vision for 2025’ presented requirements for 50% faster UK project delivery benchmarked against 2013 industry performance. Annual data had revealed a downward trend in UK construction project time predictability. 2012 KPI’s reported the lowest figures over a 12 year period, when no more than 34% of UK construction projects were delivered on or before their original planned project end date with 42% of construction phases delivered on or before their original planned completion date (Gledson and Greenwood, 2014). The latest KPI data has identified increases across all measures of time predictability, however more than half of UK construction projects continue to exceed their agreed time schedules.

¹ barry.gledson@northumbria.ac.uk

Table 1: Construction time predictability for years 2007 - 2013 - percentage of projects and phases delivered on time or better. Table adapted from Constructing Excellence (2014)

KPI	2007	2008	2009	2010	2011	2012	2013
Predictability Time: Project	58	45	45	43	45	34	45
Predictability Time: Design	58	58	53	69	51	48	52
Predictability Time: Construction	65	58	59	57	60	42	67

LITERATURE REVIEW

Conventional construction planning

Construction planning is required to determine project duration against which performance is measured. Planning is performed in order to decide upon organisational goals and project means and solutions (Winch and Kelsey, 2005). Plans have traditionally been communicated in a variety of formats, most frequently in bar charts mediums using computer aided scheduling software to perform critical path calculations. Construction projects have a need for systematic and rigorous front-end planning, yet managers are encouraged to question standard solutions (Greenwood and Gledson, 2012). Construction programmes can suffer from systems complexity with the large volume of Tasks Per Programme (TPP) being one such indicator of complexity. This has been illustrated in previous research efforts where Liston, Fischer and Winograd, (2001) used a typical construction programme that contained 8000 tasks, and Dawood (2010) used a quantitative technique to demonstrate that 15,631 tasks were identified across two construction projects. In addition to TPP volume, another indicator of programme complexity is the multiple logical dependencies and different dependency types (such as Finish to Start; Start to Start; Start to Start with Lag) that are applied to each individual task, meaning that increases in the number of possible logical iterations also increase the complexity of the programme.

Communication and problems of transactional distance

Effective communication is a significant factor in any successful project (Gorse and Emmitt, 2007; 2009) Communication involves iterative processes (Emmitt, 2010) containing multiple components set against a background of 'noise'. Components include: the message; any necessary coding of the message; senders; receivers; channels of communication; and some form of feedback to identify communication comprehension. Although senders can consider that they have sent clear messages there always remains doubts of whether such messages have been received and processed as intended. Within literature various communication models have been developed including early simple linear Sender-Message-Channel-Receiver models (Shannon and Weaver, 1949; Berlo, 1960) and later Encode-Transmit-Receive-Decode, transactional models of communication (Barnlund, 2008) that recognised the importance of coding, communication noise, and feedback to test comprehension. Communication effectiveness relies on the success of closing the transactional distance between parties. 'Transactional distance' theory was developed by Moore (1993) and is defined as being the psychological distance that exists between people when communicating (Barrett, 2002 as cited by Soetanto *et al.*, 2014). All forms of construction production information, such as drawings, specifications and schedules, are generated by a sender attempting to communicate a message. Often the receiver of production information struggles to understand exactly what has been updated, or

what is communicated (Li *et al.*, 2011). One benefit of the use of Building Information Modelling (BIM) is the resultant improvement in the quality of production information (Crotty, 2012) and whilst its use helps close the transactional distance between construction actors, use of 4D BIM can reduce this gap further.

Closing transaction distance through the diffusion of 4D BIM innovation

BIM conforms to Everett Rogers definition of an innovation - “*an idea, practice or object that is perceived as new by an individual or other unit of adoption*”, where diffusion is the “*process through which an innovation is communicated through certain channels and adopted over time among the members of a social system*” (Rogers, 2003). A systematic review of innovation diffusion literature undertaken by Reza Hosseini *et al.*, (2015) identified construction innovation core attributes: being new to the implementing institution(s); of a non-trivial change in nature; forecasting process related benefits; generating value to organisational strategic outcomes; providing competitive advantages; subject to much uncertainty and risk; and importing practices from outside of construction. Much of these attributes apply to the use of 4D BIM. Literature considers the use of 4D BIM innovation, where the time dimension is linked to the 3D-model ($x + y + z + t$) as a useful addition to construction planning (Koo and Fischer, 2000). As noted, construction planners traditionally use a programme in order to communicate their own message, i.e. the plan. However this medium can get in the way of the message (Cullen and Nankervis, 1985). 4D planning involves making use of 4D BIM innovation to improve construction planning techniques. 4D planning is when a time schedule is linked to a 3D-model to enable visualisation of the time and space relationships of construction activities (Liston *et al.*, 2001; Büchmann-Slorup and Andersson 2010) to analyse the construction schedule to assess its implementation (Koo and Fischer, 2000; Mahalingam, Kashyap and Mahajan, 2010; Trebbe, Hartmann and Dorée, 2015) and help reduce scheduling errors through plan interrogation and validation. 4D BIM innovation aims to amplify the understanding of the construction plan through 4D visualisations which are “*simpler representations of the development of the project and can be used by a wider variety of project participants at varying levels of skills and experience*” (Mahalingam, Kashyap and Mahajan, 2010).

Problems of resistance and diffusion

Several researchers consider there to be an increase in the uptake of construction professionals using 4D BIM innovation (Hartmann, and Fischer, 2007; Hartmann, Gao, and Fischer, 2008; Trebbe, Hartmann and Dorée, 2015). Mahalingam, Kashyap, and Mahajan (2010) noted the gap between the theoretical benefits, of communication and operational efficiencies espoused within the literature, and actual use within industry and note that because of the practical difficulties of implementing 4D BIM there is a need to further explore implementation and perceptions of intended users towards this innovation. Organisational and project related barriers have impeded the widespread diffusion of 4D BIM innovation and despite the apparent advantages afforded by 4D BIM, it should be noted that any misunderstanding by planners and construction practitioners will impede diffusion (Li *et al.*, 2008), equally there is likely to be human resistance to such innovation. One significant frustration for many practitioners is the challenges faced when changes in working processes are introduced, particularly in terms of having to learn new software, after years of gaining a particular expertise. Construction industry professionals such as construction planners are likely to strongly identify themselves by the professional and technical expertise skills that they have acquired over a long period of time synthesising their

experiences over each project and Dodgson and Gann (2010) identify that such disruptive innovations are likely to disturb the delicate balance and the implicit social contracts that lie between organisations and their employees. Mahalingam, Kashyap, and Mahajan (2010) identified that organisational and project related barriers have impeded the widespread diffusion of 4D BIM and warned that despite these benefits the innovation “*might not diffuse through the construction industry unless 4D modelling and analysis is integrated into existing project planning approaches*”. Thus there is then a need to consider 4D BIM innovation from the perspective of innovation diffusion theory.

Previous research into the implementation and use of 4D BIM and virtual construction (VC) found high levels of BIM awareness with some experience of use of VC, primarily for work winning, methods planning, and the visualisation and validation of construction processes (Gledson and Greenwood, 2014). These researchers identified an opportunity for further research: the need to see if the potential benefits of 4D planning are being actualised to provide greater efficiency and effectiveness over traditional methods of planning construction projects. An aim of this study is to address these opportunities for further research.

RESEARCH METHOD AND FINDINGS

The target population of the study was all construction disciplines working for or with contracting organisations delivering construction projects across any tier of the UK construction industry. An online web hosted questionnaire survey was considered to be an appropriate means of data collection and purposive sampling was employed. The survey was opened for in April 2014 and collected 80 full responses. An additional 51 partial responses were received although these were excluded from analysis due to their incompleteness. The 5 part questionnaire contained 49 questions which closely followed several of Rogers (2003) key variables, adapted in Figure 1 to determine the rate of innovation adoption: These included the relative advantages of 4D BIM innovation against functions of construction planning; the relative advantages of 4D BIM innovation against stages of the construction planning process; issues of compatibility, complexity, trialability and observability; types of innovation decisions made, and information regarding communication channels. Because of page limitations only summary results have been reported in this paper.

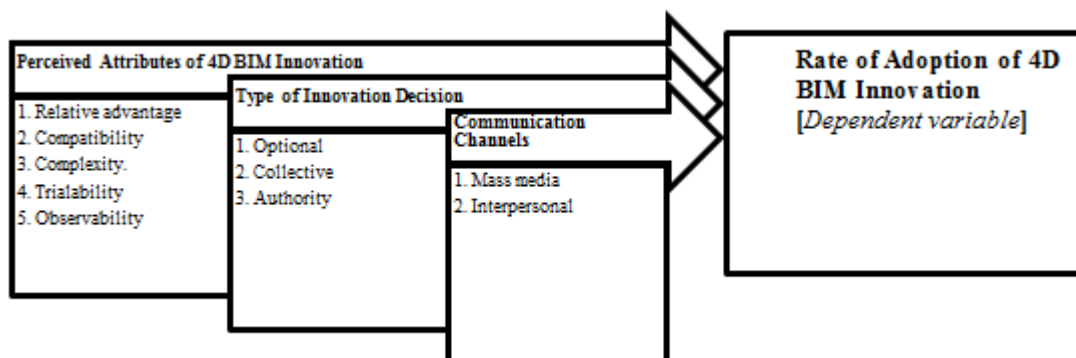


Figure 1: Variables determining the rate of 4D BIM innovation adoption. Adapted from Rogers (2003)

Findings

Rate of Adoption

In response to Q14 ‘Do you currently use 4D BIM in your construction planning practices?’ 56.3% (n = 45) of the total respondents confirmed use. Respondents who answered ‘NO’ were then asked Q16 ‘Are you aware of anyone in your organisation who currently uses 4D BIM in their construction planning practices?’ 11.3% of the total respondents (n = 9) confirmed use, meaning 67.6% (n = 54) of respondents use/are aware of someone in their organisation that uses 4D BIM innovation. The remaining 32.4% (n = 26) do not use and are not aware of anyone in their organisation that uses 4D BIM innovation. Focussing only on respondents who self identified as adopters, these were asked in which year they first became aware of 4D BIM (Q12) and in which year they adopted 4D BIM innovation in their construction planning practices for the first time (Q15). The earliest year of awareness was 1998, the mean 2009 and the median 2010. The earliest year of adoption was 2002, the mean 2011 and the median 2013. [Note: For those only reporting upon awareness of others in their organisation that have adopted 4D BIM, both the mean and median years were 2013].

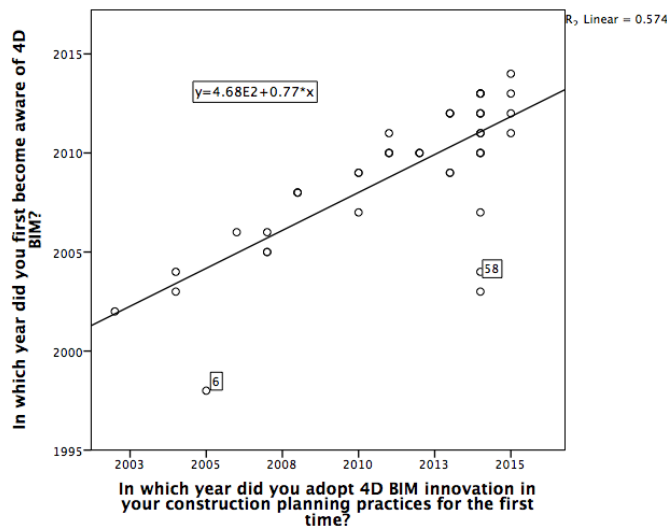


Figure 2: Year of awareness vs. year of adoption for respondents self identifying as adopters

The Pearson’s Correlation for these two measures is .758 and the 2-tailed statistic is .000, which is significant at the 0.01 level. The R^2 Statistic is 0.574 as shown in Figure 2. The data revealed a handful of interesting outliers all of whom worked for large contracting organisations of 250+ employees. The earliest recorded awareness of 4D BIM in this sample was respondent 6 who first became aware in 1998 but did not adopt until 2005 and then only because of a company (Authority) decision. The longest period of time between awareness and adoption was observed in respondent 58 who first became aware in 2003 but did not adopt until 2014, a lag of 11 years and adoption was described as a collective decision. Whilst these individual data points could be isolated to argue the slow diffusion of technological and process based innovations in the construction industry, the usual time lag recorded between awareness and adoption was recorded as being between 1.75 – 3.00 years.

Decision Types

Several questions focussed on decision types. Q44 asked the respondent to ‘confirm if a [subsequent] decision has been made to adopt or reject the use of 4D BIM for the planning of construction work’ and then depending upon the response Q45/46 asked

which type of decision was made to adopt/reject 4D BIM Innovation. 65.0% of respondents (n = 52) confirmed that a decision had been made to adopt 4D BIM for the planning of construction work, with 1.3% (n = 1) of respondents conforming that a decision had been made to reject 4D BIM innovation. 33.8% (n = 27) of respondents selected the undecided/no decision made option. Rogers (2003) categorisation of decision types were specified as: '*Optional Decisions*', where a decision was made by the individual; '*Collective Decisions*' made by consensus; and '*Authority Decisions*', made by organisational upper management. A majority of the adopters, 32.5% (n = 26) identified that the decision to adopt had been an 'authority decision', with the collective decision making being the next most frequent option with 18.8% (n = 15) followed by individual 'optional' decision making with 13.8% (n = 11) of the responses.

Relative advantages of 4D BIM against construction planning functions

The functions of construction planning practice were identified from a review of the wider construction planning literature: (A) *work winning*; (B) *design interrogation*; (C) *planning construction methods*; (D) *visualising the construction process*; (E) *facilitating understanding of the construction process*; (F) *validating the time schedule*; (G) *location based planning*; (H) *progress reporting*; (I) *site layout planning (positions)*; (J) *logistics planning (movements)*; (K) *communicating working space*; and (L) *safety planning*. 5-point Likert scales were used to measure strength of agreement as to where 4D BIM could offer a relative advantage against these factors and the online questionnaire was designed to randomise the response options to avoid response set tendency. Spearman's Rho was used to establish correlation and significance in the strength of the relationships between these variables. Table 2 identifies the many significant associations, whilst the largest correlations are between (J) logistics planning (movements) and (K) the communication of working space (.668) and between (B) interrogating design and (D) visualising the construction process (.576), meaning that 4D BIM is considered to be more effective than traditional construction planning for these purposes.

Relative advantages of 4D BIM against construction planning process

The same method of analysis was used to assess the relative advantages of 4D BIM against the construction planning process which was identified in the literature as: (A) *gathering information*; (B) *identifying activities*; (C) *assessing activity durations*; (D) *planning the logical dependencies*; (E) *planning the construction sequence*; (F) *communicating the construction plan*; and (G) *communicating project timescales*. Table 3 again identifies many significant associations, however the largest correlations are between (D) planning logical dependencies and (E) planning construction sequence (.643), and between (A) gathering information and (E) planning construction sequence (.566) again meaning that 4D BIM is deemed to be more effective than traditional construction planning for these purposes.

Table 2: Functions - strength of relationships: Nonparametric Correlations. Correlation significant at the 0.05 level (2-tailed)*. Correlation significant at the 0.01 level (2-tailed)**.

		A	B	C	D	E	F	G	H	I	J	K	L
A	CC	1.000	.347**	.347**	.485**	.279*	.329**	.282*	.297**	.440**	.325**	.316**	.387**
	Sig	.	0.002	0.002	0.000	0.012	0.003	0.011	0.007	0.000	0.003	0.004	0.000
B	CC	.347**	1.000	.438**	.576**	.280*	.323**	.289**	.406**	0.219	0.154	.328**	0.110
	Sig	0.002	.	0.000	0.000	0.012	0.004	0.009	0.000	0.051	0.174	0.003	0.329
C	CC	.347**	.438**	1.000	.467**	.488**	.424**	.366**	.485**	.252*	.322**	.335**	.427**
	Sig	0.002	0.000	.	0.000	0.000	0.000	0.001	0.000	0.024	0.004	0.002	0.000
D	CC	.485**	.576**	.467**	1.000	.451**	.380**	.335**	.422**	.309**	0.217	.345**	0.177
	Sig	0.000	0.000	0.000	.	0.000	0.001	0.002	0.000	0.005	0.053	0.002	0.117
E	CC	.279*	.280*	.488**	.451**	1.000	.280*	.419**	.408**	.295**	.478**	.538**	.253*
	Sig	0.012	0.012	0.000	0.000	.	0.012	0.000	0.000	0.008	0.000	0.000	0.024
F	CC	.329**	.323**	.424**	.380**	.280*	1.000	.369**	.473**	0.006	.266*	.248*	.352**
	Sig	0.003	0.004	0.000	0.001	0.012	.	0.001	0.000	0.957	0.017	0.027	0.001
G	CC	.282*	.289**	.366**	.335**	.419**	.369**	1.000	.280*	.343**	.293**	.426**	.260*
	Sig	0.011	0.009	0.001	0.002	0.000	0.001	.	0.012	0.002	0.008	0.000	0.020
H	CC	.297**	.406**	.485**	.422**	.408**	.473**	.280*	1.000	.232*	.329**	.307**	.468**
	Sig	0.007	0.000	0.000	0.000	0.000	0.000	0.012	.	0.039	0.003	0.006	0.000
I	CC	.440**	0.219	.252*	.309**	.295**	0.006	.343**	.232*	1.000	.516**	.475**	.251*
	Sig	0.000	0.051	0.024	0.005	0.008	0.957	0.002	0.039	.	0.000	0.000	0.025
J	CC	.325**	0.154	.322**	0.217	.478**	.266*	.293**	.329**	.516**	1.000	.668**	.260*
	Sig	0.003	0.174	0.004	0.053	0.000	0.017	0.008	0.003	0.000	.	0.000	0.020
K	CC	.316**	.328**	.335**	.345**	.538**	.248*	.426**	.307**	.475**	.668**	1.000	.346**
	Sig	0.004	0.003	0.002	0.002	0.000	0.027	0.000	0.006	0.000	0.000	.	0.002
L	CC	.387**	0.110	.427**	0.177	.253*	.352**	.260*	.468**	.251*	.260*	.346**	1.000
	Sig	0.000	0.329	0.000	0.117	0.024	0.001	0.020	0.000	0.025	0.020	0.002	.

Table 3: Processes - strength of relationships: Nonparametric Correlations. Correlation significant at the 0.05 level (2-tailed)*. Correlation significant at the 0.01 level (2-tailed)**.

		A	B	C	D	E	F	G
A	CC	1.000	.527**	.520**	.434**	.566**	.250*	.488**
	Sig	.	0.000	0.000	0.000	0.000	0.026	0.000
B	CC	.527**	1.000	.387**	.392**	.521**	.344**	.407**
	Sig	0.000	.	0.000	0.000	0.000	0.002	0.000
C	CC	.520**	.387**	1.000	.452**	.468**	.228*	.484**
	Sig	0.000	0.000	.	0.000	0.000	0.042	0.000
D	CC	.434**	.392**	.452**	1.000	.643**	.402**	.500**
	Sig	0.000	0.000	0.000	.	0.000	0.000	0.000
E	CC	.566**	.521**	.468**	.643**	1.000	.414**	.391**
	Sig	0.000	0.000	0.000	0.000	.	0.000	0.000
F	CC	.250*	.344**	.228*	.402**	.414**	1.000	.389**
	Sig	0.026	0.002	0.042	0.000	0.000	.	0.000
G	CC	.488**	.407**	.484**	.500**	.391**	.389**	1.000
	Sig	0.000	0.000	0.000	0.000	0.000	0.000	.

Compatibility, complexity, trialability and observability

Several statements were posed relating to these aspects, and strength of agreement was again measured using 5-point Likert scales. To measure compatibility, Q38 stated ‘*the use of 4D BIM is compatible with our current practice of construction planning*’ and 57.5% (n = 46) in agreement with this statement with 23.8% of respondents (n = 19) remaining neutral, and the remainder disagreeing. Several measures of complexity as a barrier to 4D BIM adoption were considered and the direction of this trend was usually consistent. Q39 was worded ‘*4D BIM methods would be difficult to learn*’ and 40% (n = 32) disagreed with this statement, with 36.3% (n=29) remained neutral, and the remainder agreeing. Q40 ‘*4D BIM methods would be difficult for planners to understand*’ also found a majority 56.3% (n = 45) disagreeing with this statement, with 26.3% (n=21) remaining neutral, and the remainder agreeing. Q41 ‘*The training required in order to learn 4D BIM methods would be complicated*’ was similar with 45.1% (n = 36) disagreed with this statement, however in this question more respondents 32.5% (n=26) agreed with this statement than the 22.5% (n = 18) that remaining neutral. To measure trialability Q42 stated ‘*4D BIM methods would have to be experimented with before using to plan real construction work*’ and 55% (n = 44) agreed with this statement with 25.0% (n = 20) disagreeing. To measure observability Q43 stated ‘*It is easy to see the impact that 4D BIM has on construction planning effectiveness*’ and 70.0% (n = 56) agreed with this statement with 20.0% (n = 16) remaining neutral and the remainder disagreeing.

Communication channels

Respondents were asked two questions in relation to communication channels. Q47 asked ‘*Please select your preference for obtaining information about 4D BIM*’ and Q48 asked ‘*Which of the following has had/would have the biggest impact on your own personal decision to adopt or reject the use of 4D BIM*’ The same two response options were provided for both questions ‘*External Sources, i.e.: Mass media including websites, journals, magazines; government*’ and ‘*Internal sources i.e.: Colleagues, peers, workmates or interpersonal networks*’. At the outset of this study a set of hypotheses was formed and able to be tested:

H₀: *There is no relationship between a preferred source of information about 4D BIM and the impact of such influences in any adoption or rejection decision.*

H_A: *There is a relationship between a preferred source of information about 4D BIM and the impact of such influences in any adoption or rejection decision.*

Conditions for a Chi-Square (X^2) test of independence were met, and all 80 cases could be used. A test statistic of .000 was given meaning that H₀ could be rejected in favour of H_A: *There is a relationship between a preferred source of information about 4D BIM and the impact of such influences in any adoption or rejection decision.* A review of the cross-tabulation results confirmed the strongest association (43.8%) was between external sources for information preference and internal influences for impact upon decision making, which supports one of Rogers (2003) key generalizations (5-13) that “*mass media channels are relatively more important at the knowledge stage and interpersonal channels are relatively more important at the persuasion stage in the innovation-decision process*”.

CONCLUSIONS

Results indicate a growing rate of 4D BIM innovation adoption for the planning of construction projects with a typical lag of 1.75 - 3 years between awareness and first

use. Innovation adoption decisions are then typically authority decisions made by organisational upper management and exploration of the data at individual case level also reveals slow rates of diffusion for those with early awareness of this innovation but without these authority adoption decisions. Many construction planning functions and stages of the construction planning process are considered to be more effective using 4D BIM than current construction planning practices. Whilst compatibility and observability remain important aspects of any innovation adoption, concerns over training complexity and opportunities for trialling the innovation seem more prominent as barriers to 4D BIM adoption. The study also confirms Rogers (2003) assertion that it is “*interpersonal communication with near peers drives the diffusion process*” in that adoption/rejection decisions are more likely to be influenced by internal factors than external factors. With additional data, analysis will be extended to permit further inferential statistical analysis to explore associations between the extent and nature of 4D BIM use for construction planning and the characteristics of user organisations such as size and BIM maturity.

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INCORPORATION OF EXPERT REASONING INTO THE BIM-BASED COST ESTIMATING PROCESS

Shen Xu¹, Kecheng Liu² and Llewellyn C. M. Tang³

^{1 and 2}University of Reading, Reading, UK

³University of Nottingham, Ningbo, China

The analytical cost estimation is an efficient and robust data based approach. Yet, there are two key issues associated with analytical cost estimation; the need to make sure that practice standards are adhered to and the implementation of subjective recommendations. The degree of precise detail, and the intricacy of standards and expert insight is a hindrance to its computerisation, as a result of complicated software development schedules and increasing expenses. A rule based semantic method is utilised as a model and is demonstrated as a way to tackle these problems. The investigation of BIM-based cost estimation confirmed that industry foundation classes (IFC) can provide construction project semantics but incapable of relating domain semantics and pragmatics. Our model is founded upon the belief that three components are necessary to gain a full awareness of the domain which is being computerised; the information type which is to be assessed for compatibility (syntax), the definition for the pricing domain (semantics), and the precise implantation environment for the standards being taken into account (pragmatics). Moreover, organizational semiotics is employed to uncover the semantic components of cost estimation from a procedural standpoint and suggest an improved knowledge based system. This report outlines the way in which the proposed approach has been verified, by employing a selection of codes created by the prototype of the data based model. The standards of practice which have been establish are then verified, in accordance with actual building information gained from IFC. The utilisation of this approach has significantly advanced the procedure of automating professional costing practice within a BIM context. These pleasing outcomes demonstrate that, by implementing this model, the reasoning ability can be used by the BIM context and the restrictions around the application of BIM will be reduced.

Keywords: rule-based reasoning, semantic web ontology, organizational semiotics, industry foundation classes, quantity surveying.

INTRODUCTION

The guarantee of compatibility for analytical cost estimation is one of the most prominent issues for experts within the industry, particularly when it comes to ensuring compatibility against the standards of practice which regulate the sector (Beach *et al.* 2015). Whilst the employment of BIM to aid cost estimation has become a lot more regular, the efficient transformation of intricate and non-binary text based standards (created to be interpretable to specialists) into machine executable code continues to be a tricky process. Moreover, the subjective decisions of estimators also play an essential part (Cheng *et al.* 2009) and the level of access to historical information is similarly essential. Therefore, it is, by its very nature, a subjective

¹ s.xu@pgr.reading.ac.uk

process, and the utilisation of advanced problem solving is vital whether or not sophisticated pricing models or basic methods are employed. It is broadly utilised and perceived to be a solution for the oft-disregarded issue of cost estimation (Beltramo 1988; Stapel 2002).

This study aims to discuss the most prominent restrictions associated with the creation of BIM models for cost estimation functions. The use of a fresh and far reaching viewpoint is necessary, because it enables the use of reasoned capacity to address standards of practice, compatibility challenges, and issues relating to subjective choices. The intricate components of standards of practice and specialist insight means that a more complex software development framework is necessary. To be precise, this is needed to address the intricacies associated with explaining the objectives of industry specific standards to software experts and, equally, verifying the software resources created by domain specialists. The consequence of this model is that it tends to leave pricing systems restricted or fully closed.

The main objective of this research is to create, assess, and verify a generic rule based semantic expert cost estimating model. The authors predict that there will be two primary benefits for systems which employ our new model: (1) the capability of domain specialists to comprehend and upgrade the standards of practice and level of insight within an open software architecture, and (2) the expanded awareness of the fact that analytical cost estimating is equivalent to rule based reasoning. This enables verification of the system to be carried out with a much greater degree of accuracy.

STATE-OF-ART OF BIM-BASED COST ESTIMATION

There has been efforts in the past towards performing automatic cost estimation within BIM, thus an extensive exploration of intelligent solution for cost estimation is necessary (Abanda *et al.* 2011; Fidan *et al.* 2011; Lee *et al.* 2014; Ma and Wei 2012; Staub-french *et al.* 2003). It is also a good idea to point out that the filtered reports are founded upon a literature review of more than 100 papers. They were all discovered using key terms like semantics model, construction, design, building, built-environment, ontology, resource description framework, (RDF) semantic web ontology language (OWL), IFC, and more (all dated from 2002-2014).

The research of Staub-French *et al.* (2003) has already outlined an ontology of building characteristics which can help specialists to carry out accurate price predictions. The application approach can be outlined as creating the characteristics of the component, using demonstrations of building product models (such as IFC models), pinpointing the design specifics of the component, and applying the insights of specialists in a project-subjective manner, in order to evaluate or integrate actions for building components. Once this has been done, the expenses are adapted in accordance with the findings.

The work of Abanda *et al.* (2003) explores the work related expenses in Cameroon, where they are used to employing basic data engineering methods to construct UML models of work expenses, and then applies these in OWL. Then, utilising semantic web rule language (SWRL) for OWL enables various different task locations to be identified and a suitable work expense estimation can be chosen for the location in question.

A database system, founded upon an ontology of risk incident, was created by Fidan *et al.* (2011), in order to estimate the chance of expense overruns. The language has not been specified and the evaluation of expense overruns are beyond the reach of this

study. This is because its primary aim is related to analytical cost estimation, even if expense overrun calculations are also a kind of estimation.

According to Ma and Wei (2012), it is useful to employ a system which moves IFC information to Owl. This transition means that it allows the reasoning capability to instantly categorise building construction resources into expense items and automatic amounts, before calculating the overall cost summary. Yet, the pricing phase is still not present, because (as Ma and Wei make clear), the expense items can always actively quote market prices, which negates the need for item pricing altogether. Then again, OWL is the application method, but the ontological/semantic method is founded upon IFC.

As explained by Lee *et al.* (2014), the searching procedure for the most suitable work related items associated with expense prediction can be identified with the use of OWL and SWRL. The given information is withdrawn from an IfcXML file position, so that semantic reasoning can be applied for the ontology of working conditions. These file types offer data about dimensions, thickness, technique, materials, width, size, and more, in order to clearly identify the work items needed for expense predictions.

On the other hand, commercial software for cost estimation, as is outlined by Eastman *et al.* (2011, p.220), *“There is no single BIM resource which can offer the same functions as a spreadsheet or a cost prediction service, so expert estimators are obligated to discover an approach which is suitable for their precise kind of prediction procedure.”* The three key choices for cost estimation, founded upon BIM, are as follows; (1) move building object amounts to prediction software, (2) employ a BIM quantity take off resource, or (3) connect the BIM resource to the prediction software. These choices offer varying degrees of interoperability. For the first two choices, information is withdrawn from the model and transported using a format which can be easily interpreted by cost estimating programs. For instance, there are a number of programs which are compatible with cost estimation processes; CATO, CostX, and Nomitech are among them (Exactal 2013; Nomitech 2013).

The computerisation achievements of the construction sector are generally reliant upon the upcoming technologies of the next generation internet. This is commonly called the ontology/knowledge demonstration and it has the potential to usher in a great deal of innovation. One prominent characteristic of this ontology/knowledge based idiom is the need to be compatible with interoperability between software applications, inclusive of web based services and intelligent programs. If the construction sector is used as an example, it should be clear that the tools needed to introduce interoperability between software applications is the ISO-10303 Standard Exchange of Product Data (STEP). In fact, the IFC was designed to be a building information model for the construction sector and is founded upon tools created by STEP. The semantic heavy model is responsible for enhancing the condition of building data via the employment of semantic technologies. In other words, the aim is to expand upon the current building information using machine processable data and ontologies.

The reason that OWL is frequently recommend as the best knowledge representation language (particularly for aesthetic briefs) is because it is efficient, popular, and now broadly supported. It is worth noting that this situation does not speak of any system based issues with any of the other languages. However, it continues to be the case that

the basic knowledge engineering procedure appears to be lacking in terms of an integration of semantics and pragmatics (Grzybek *et al.* 2014).

This chapter has explored subjects associated with the BIM-based cost estimation sector. It has proposed improved and more innovative methods, particularly when it comes to the ontology utilised within the construction industry. Yet, there is as yet no single study which has managed to integrate the suggested methods into an overarching model with the ability to take into account all relevant viewpoints. Whilst a number of the most important studies associated with costing emphasise a semantic foundation within the domain (Ma *et al.* 2013; Nepal *et al.* 2012), it is believed that a full account of all the relevant viewpoints has to incorporate an informational format which can be assessed for compatibility (syntax) the definition of the pricing domain (semantics), and the precise implementation environment for the standards which are being evaluated (pragmatics). This is particularly vital for the construction sector, because there is a developing popularity for reverse engineering the semantics of the domain from its main data storage type, which are the IFCs. It is also believed that this is not the best approach, as they IFCs were created to be a data storage function and cannot fully demonstrate the right series of semantics for the construction management sector. The assimilation of these three viewpoints is the most important advantage offered by our approach. It is hoped that it will continue to expand the reasoning capacity of the pricing models used alongside BIM, particularly in comparison to similar models outlined in this chapter, and that it will serve as an advanced progression. In our opinion, this new approach offers plenty of benefits to specialists who use BIM.

DEVELOPMENT OF A FRAMEWORK FOR BIM-BASED COST ESTIMATION

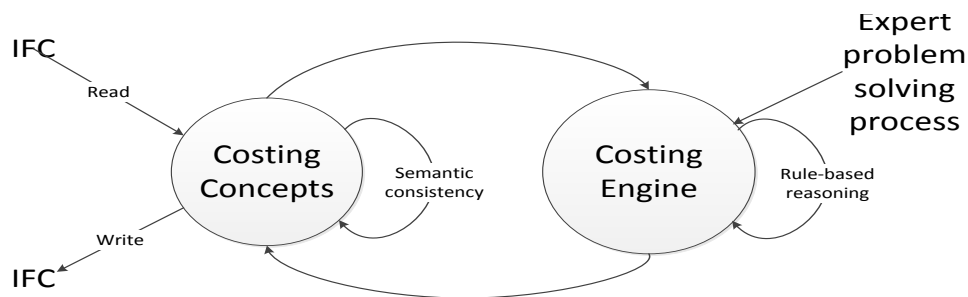


Figure 1 A proposed framework of costing professional services under BIM environment

According to Figure 1, the suggested model demonstrates a heterogeneous method to be used in an abstract context. It directs the way in which the designed model should be employed alongside a BIM scenario. The outlined model demonstrates the fact that IFC informational structures are deconstructed for building data and are expected to carry the outcomes of cost prediction. This is verified by our own semiotics system evaluation, carried out in line with IFC (BuildingSMART 2013; ISO 16739 2013) and cost estimation standards (The Royal Institution of Chartered Surveyors 2007), and which provides a semantic heavy model for building data, but does not have enough specialist reasoning (Venugopal 2012). Therefore, IFC is easily leveraged as the primary data collector for building construction tasks. Yet, domain ontology is used to demonstrate specialist insights.

From a theoretical perspective, knowledge representation is a concept based approach created to aid logical programming. At the heart of knowledge lies the trio of predicates, objects, and subjects. In terms of the OWL, it primarily subjects as categories, predicates as object characteristics, and objects as categories too. This report uses problem based briefs to source all the semantic components from standards (The Royal Institution of Chartered Surveyors 2007, 2011), but semantic evaluation emphasises the task components. This leads to an enhancement of the input and outtake of these tasks, because all of the tasks are linked, and can be used to create an ontological table of quantity surveying. The semantic evaluation strategies have been influenced by organisational semiotics (Liu 2000).

There are two key motivations for utilising organisational semiotics. The first relates to the fact that the varying ontological idioms can be tricky; it is thought that, without a knowledge assimilated process of expense prediction, this knowledge is considered 'lost in the system.' It can only be recovered and utilised with additional expense. The semiotic phases then are able to clearly demonstrate syntax, semantic, pragmatic, and cultural viewpoints. In fact, semantic evaluation can assimilate semantics and pragmatics using a series of complex methods (Stamper 1991). Thus, the basic guidelines can be made even simpler, so that they are able to aid expert tasks at a detail specific level. For instance, they can explain, outline, highlight, choose, and adapt information throughout the expert cost estimation phase. Secondly, due to the fast paced evolution and widespread use of computers, cost predictions now require a technology based upgrade approach to prediction. This methodology must include a degree of human input, which is they creators of this research argue that analysis experts should have to use suitable and methodical analytics strategies within information system engineering and related sectors. It should also be noted that this is not a claim that technology can be a substitute for human specialists, but rather that technology can be integrated into enterprises.

Within a practical context, not all of the building characteristics can be assessed alongside a modelling idiom. This further emphasises the value of using reasoning capacity for domain specialists, particularly if they are trying to handle complex scenarios by employing standards and deductions. Moreover, normative evaluation verifies the guidelines which regulate the actions of a cost estimator as they are carrying out analytical cost estimation. The advanced problem solving strategy is provided by normative withdrawal from domain standards and the ontological renewal of earlier studies.

DEPLOYMENT AND IMPLEMENTATION OF METHODOLOGY

To apply our model and allow for its verification within the selected scenario, a prototype of application was created to provide accurate expense predication outcomes. The employment of our model was carried out in three key phases: (1) withdrawal of meta-data from standards of practice reports (The Royal Institution of Chartered Surveyors 2011), (2) identifying semantic mappings, and (3) the application of specific strategies.

Semantic Evaluation – to conduct this phase of the model, the Order of Cost Estimation (The Royal Institution of Chartered Surveyors 2007), and the best practices associated with cost prediction (Evans and Peck 2008; Isakowitz 2002; Schinnerer 2007; Sinclair *et al.* 2002; Tan and Makwasha 2010) have been analysed. There are a total of 123 meta-data components which have been withdrawn.

Semantic Mapping – to conduct this phase of the model, the mapping between the key terms utilised for standards of practice and the idiom of the IFCs has been implemented. The outcomes of the mapping are outlined in Table 9.

Table 1 Semantic units mapping

Documents	Total IFC entity	Number of attributes	Number of relationships
Order of Cost Estimation	22	27	8
New Rules of Measurement	42	59	22

Application of Strategies – the following phase of the model is based on the application of strategies already highlight by the semantic evaluation. These strategies form the precise steps which must be carried out by specialists and they are all linked with a different kind of data. Moreover, in order to verify these strategies (a total of 13), a question based survey has been created to enquire about specialist reasoning directives.

The next phase of system building takes the form of a confirmation procedure for pricing insights. Thus, officially identified ontologies can be confirmed via the use of reasoning tools. The Protégé offers this function via the use of inbuilt reasoners like FACT++, Hermit, and Pellet (Bechhofer 2004; Shearer *et al.* 2008; Sirin *et al.* 2007). The accuracy of all the tools has been evaluated and an unpredictable insight was offered and highlighted by the reasoner.

The final aspect of our research focuses on the confirmation of guidelines which have been developed for the study. This is achieved via the transformation of norms within a logical program. The engine has been given an extra level of precision, so as to be as accurate as possible and to be compatible with many different kinds of standards of practice. The abilities of this engine include the following; the capability to question and upgrade the semantic framework, the capability to deduct non-existent building components, and the capability to entreat pricing predictions in line with the given reasoning directives and phases.

To verify the results of the cost estimation model, it will be tested alongside an active construction task. To make this happen, the model will be linked with a predefined modification of IFC. For the purposes of this research, an IFC parser will be applied. This is because it can interpret entities within the IFC physical file positions 2 and 3 and transform RDF file formats – refer to Figure 2 for an example of a transformed IFC physical file.

```

<!-- #ifcwall_15478 -->
<owl:NamedIndividual rdf:about="&untitled-ontology-12;ifcwall_15478">
  <has_id rdf:datatype="&xsd:string">15478</has_id>
  <ace_lexicon:PN_sg rdf:datatype="&xsd:string">ifcWall_SW-007</ace_lexicon:PN_sg>
  <has_type rdf:datatype="&xsd:string">external wall</has_type>
  <name rdf:datatype="&xsd:string">sw-007</name>
  <has_constructionworkresult rdf:resource="&untitled-ontology-12;brick1"/>
  <has_quantity rdf:resource="&untitled-ontology-12;ifcquantityarea_33501"/>
  <has_quantity rdf:resource="&untitled-ontology-12;ifcquantitylength_33505"/>
  <has_quantity rdf:resource="&untitled-ontology-12;ifcquantitylength_33506"/>
  <has_quantity rdf:resource="&untitled-ontology-12;ifcquantitylength_33507"/>
  <has_quantity rdf:resource="&untitled-ontology-12;ifcquantityvolume_33499"/>
  <has_spacefunction rdf:resource="&untitled-ontology-12;ifcspace_1234568"/>
</owl:NamedIndividual>

```

Figure 2 IFC Entity represented by Web Ontology

RESULTS

Once the construction of the pricing model was finished, it was tested alongside an active building task. It is important to note that an IFC model of development for a residential venture was employed within this study. For the purposes of this research, a two floor villa type building is the central focus. The basic strategy followed pertains to that of shadowing and closely watching the relevant building costing estimations. In other words, whenever a costing system was utilised for the task in question, the model was also brought into play to provide an alternative set of results. This is how this research are able to compare and contrast two sets out outcomes from one construction scenario.

Table 2 Result summary

Procedure	Rule	Manual result	Automatic result
Decomposing	Boundary work to voids is only measured where the void exceeds 1.00m ² , and is measured by length (The Royal Institution of Chartered Surveyors 2011 p. 152).	New item will be created	√
Selecting	Measured by length (The Royal Institution of Chartered Surveyors 2011 p. 152)	Certain measuring unit will be selected	√
Establishing	Boundary work; location and method of forming described (The Royal Institution of Chartered Surveyors 2011 p. 152)	Description of items is associated	√

The number of new rules of measurement (NRM) total over 350, but for the aim of outlining the phases of this analysis, they will be restricted to those associated with wall coverings, as an example. In Table 2 Result summary, the key guidelines for deducting non-existent building characteristics on walls and their consequent outcomes are demonstrated.

Figure 3 presents the engine which has been created. From this resource, it is clear to see how standards of practice (after being transformed into guidelines via normative

evaluation) are demonstrated in line with the relevant procedures. This enables a variety of rules to be quickly assessed using the same steps. It also enables much more efficient verification. These outcomes and their comparative results, from the manual predictions, are presented in Table 2.

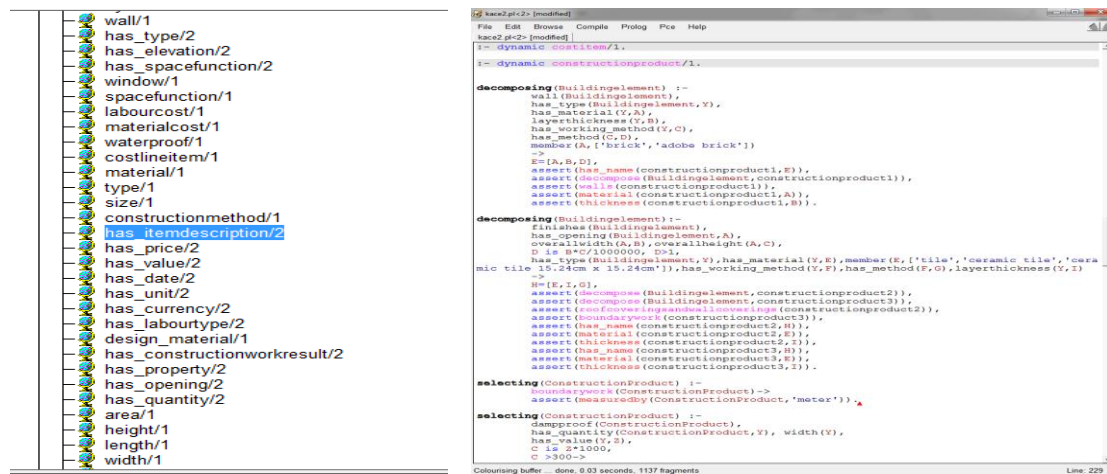


Figure 3 Rules developed

DISCUSSION AND CONCLUSION

This report has discussed our work on the creation of a rule-based semantic approach to cost estimation; the proposed model has been assessed using NRM. Furthermore, a suitable scenario has been used to show how our model enables domain specialists to pinpoint and employ a reliable cost estimation framework, based on their precise needs. The cost estimation framework that has been created as a result of our research was seen to efficiently, reliably, and successfully, carry out quantity surveying on building information, as confirmed by NRM.

In taking on this scenario, the procedures whereby which construction costing specialists employ the strategies outlined have been suitably verified. It is also clear now that they are compatible with BIM resources, being able to help them with (1) highlighting standards of practice without needing advanced software, and (2) pinpointing expert reasoning directives for individual employment. This method of upgrading standards of practice and reasoning directives is easily conducted by enhancing the semantic evaluation and semantic mapping tools developed when the system was first implemented. Moreover, the implementation of semiotic framework to evaluate BIM-based cost estimation verifies the theory that the IFC schema suffers from a deficit of reasoning capacity; this is something which is essential for advanced cost estimations. It has also allowed us to better locate additional informational items which add value to the IFC specifications, by providing increased assistance for the expense prediction procedures.

These attributes enable the functionality of the standards of practice for the framework to be altered quickly and without notice of the following; (1) sector information file formats, or (2) how the basic implementation of the guidelines function. The strategy that used involves the breakdown of specification guidelines, which made sure that the information formats and the processes relevant to a methodical strategy were a true success. Additional enhancement of the system can take the form of either (1) assimilating plug ins with the primary BIM system (for example, in the case of Bentley Microstation and ArchiCAD BIMx), in order to virtualize the costing documents, (2)

utilising an interface of precise processes and guidelines, or (3) developing automatic ontology from semantic evaluations.

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THE POTENTIAL OF BUILDING INFORMATION MODELLING (BIM) FOR IMPROVING PRODUCTIVITY IN SINGAPORE CONSTRUCTION

Evelyn Ai Lin Teo¹, George Ofori, Imelda Krisiani Tjandra and Hanjoon Kim

Department of Building, National University of Singapore, Singapore

Since 2013, it has been compulsory for practitioners to prepare proposals for building plan approval using Building Information Modelling (BIM). Moreover, raising productivity has been accorded the top priority in the current growth strategy for Singapore's economy. The utilisation of BIM in the Singapore construction industry is examined, and the possibility of deriving further benefits from the potential of BIM to improve productivity in the industry is explored. A series of interviews was carried out and an online questionnaire-based survey was undertaken in 2014 to investigate the views of practitioners on the current state of productivity and BIM application in the Singapore construction industry, and explore the potential of BIM to help in the efforts to improve productivity on construction projects. The interviewees comprised a representative cross-section of relevant parties in the industry including policy makers, contracting companies, architectural firms, a consultancy firm, a professional institution and a trade association. The respondents to the online questionnaire were contractors, architectural firms, structural engineering firms, mechanical and electrical (M&E) engineering firms and quantity surveyors. The findings suggest that the framework set up by the Singapore government has laid the necessary foundation for the implementation of BIM in the construction industry. The respondents acknowledge that BIM has the potential to enhance elements of practice beyond the preparation of models for mandatory submission, through pre-project planning, identification of documentation errors and productivity monitoring using actual construction site data. However, BIM is used more widely at the beginning stages of the projects. In the long term, much more needs to be done to use BIM in a strategic and more sophisticated manner, in particular, to further improve productivity in the industry.

Keywords: BIM, improvement, potentials, productivity, Singapore.

INTRODUCTION

Overview

The Building and Construction Authority (BCA) and buildingSMART Singapore have been promoting the use of Building Information Modelling (BIM) in the construction industry in Singapore. BCA has set a target that at least 80% of the construction industry should be using BIM widely by 2015. One of the strategies which are being implemented in order to achieve this target is the introduction of the legal provision which makes it compulsory for proposals being submitted for building plan approval to have been prepared using BIM.

¹ bdgteal@nus.edu.sg

At the broader level of the economy, one of the strategies of a government-appointed committee was to increase productivity in all sectors (Economic Strategies Committee 2010), and this has been accorded the top priority in the nation's current growth programme. The Economic Strategies Committee (2010) set a target of two to three percent per year of productivity growth over the following ten years. This has formed the background for a major programme to enhance the productivity performance of the construction industry. A major segment of this programme is to promote the application of advanced information and communication technology (ICT), especially BIM.

Hence, it is pertinent and timely to consider how the potential of BIM to enhance construction productivity can be fully exploited given the current national focus on the improvement of productivity. The results of an empirical study on productivity and BIM which formed part of a larger study on productivity, safety and BIM in the construction industry in Singapore are reported. The larger study examines the relationship between productivity and safety in Singapore's construction industry; explores how BIM can be used to improve productivity and safety performance in the industry; and seeks to develop a system using BIM to monitor and improve productivity and safety throughout the project. While a semi-quantitative approach had been used at this exploratory part of the study, a quantitative approach of productivity measurement will be used in the development of the system, which forms the next stage of the study.

The objectives of the study reported on here are to (i) assess the current situation of the construction industry in Singapore, particularly pertaining to productivity; (ii) ascertain the level of BIM implementation in the industry; (iii) find out the potential of BIM in improving productivity of the industry; and (iv) propose further actions to accelerate the implementation of BIM in the construction industry, and particularly for the purpose of improving the industry's productivity level.

BIM and productivity

BIM is defined as the development and use of a computer software model to simulate the construction and operation of a facility, resulting in a data-rich, object-oriented, intelligent and parametric digital representation of the facility (AGC 2010). Views and data can then be extracted for decision making and process improvement. According to Smith (2007), the concept of BIM is to build a building virtually, prior to building it physically, in order to work out problems, and simulate and analyse potential impacts. Smith (2007) argues that because of the use of BIM, the construction process can become more efficient and many uncertainties can be eliminated before the start of physical construction on site.

The benefits from the application of BIM in construction are well documented. They include: faster and more effective processes; better design and quality of the built item (Azhar 2011); provision of a collaboration tool for all project participants (Benjaoran and Bhokha 2010); reduction in manual efforts; time and cost savings (Gong and Caldas 2011); and identification of possible conflicts and risks that would have arisen (Gu and London 2010).

The potential of BIM to help in the efforts to enhance productivity is the main reason behind the Singapore government's policy to promote and facilitate the application of BIM including making it mandatory at the building plan approval stage (BCA 2013a). However, the literature suggests that the concept of productivity is not well understood in the construction industry. Pekuri *et al.* (2011) note that productivity is a

commonly used, but often poorly defined term. In general, productivity is defined as a ratio of output of work produced to a unit of a particular input which is used in the production process. In construction, it can be measured at various levels, including the trade, project, company or industry levels. At any of these levels, construction productivity can also be measured in many different ways. As there are many ranges and features of productivity measures, this study considers project-level productivity, which, in Singapore, is measured based on total units of output over total man-hours utilised (BCA 2013b).

During the construction phase, BIM contributes to the success of a project by enabling practitioners to effectively control schedule, budget and quality, and to reduce risks (Ku and Mills 2008). Sacks and Barak (2006) report that the total number of hours spent on three projects were reduced by 21 per cent, 55 percent and 61 per cent respectively owing to the use of 3D modelling instead of 2D. Nath *et al.* (2015) found that there could be improvements in the workflow for precast shop drawing generation using BIM. They show that there could be an overall productivity improvement of approximately 36 per cent in processing time and 38 per cent for total time.

Challenges and problems which might be encountered in the implementation of BIM are also well catalogued; some of these are relevant to the construction industry in Singapore. Rajendran and Clarke (2011) outlined a number of these challenges including the cost of BIM implementation and the training of the personnel required. BIM implementation may require some changes in the contractor selection process, since owners and contractors should now select subcontractors with BIM experience. There are also technical challenges such as the development of various construction elements to be added into BIM. On top of that, there may be resistance from some people in the firms, especially those on site, who may not believe in BIM. They suggested that for these reasons, it will take some time before BIM becomes a norm in the construction industry.

Implementation of BIM in Singapore

The government of Singapore, through the BCA, has put in place a series of initiatives under a broad programme for enhancing productivity in the construction industry. The BCA formulated a Construction Productivity Roadmap in November 2010 (BCA 2011). Its vision is to build a highly integrated and technologically advanced construction industry led by progressive firms and supported by a skilled and competent workforce by 2020. One of its strategic thrusts is “*driving adoption of BIM*”. A National BIM Steering Committee was set up in 2011 to provide a governing framework to steer the implementation of the BIM Roadmap. The committee comprises representatives of professional institutions, trade associations, major government procurement entities and regulatory agencies. The committee led the development of the “*Singapore BIM Guide*” and “*BIM Particular Conditions*” (BCA 2013c). It also provides advice to the professionals involved on the effective implementation of BIM in a construction project.

BCA (2011) outlines the various initiatives to encourage the adoption of BIM in the industry in Singapore. Among the early activities, BCA and buildingSMART Singapore, developed BIM submission templates, a design objects library and project collaboration guidelines. BCA then started the use of BIM through a number of pilot projects in 2011, working with the public sector client agencies. Subsequently, BCA has been releasing regulations making it mandatory that the submission of architectural, structural as well as mechanical and electrical plans for building works

for approval be in the BIM format. First, from 1 July 2013, all architectural plans must be submitted in BIM format; this applied to proposals for new building projects with gross floor area (GFA) of 20,000 sq. m. and above. This was followed by the mandatory requirement for BIM electronic submission (e-submission) of engineering plans of new building projects with GFA of 20,000 sq. m. since 1 July 2014. In the third phase, from 1 July 2015, all plans of new building projects with GFA of 5,000 sq. m. and above are to be submitted in BIM format.

To address the challenge to meet the high demand for skilled BIM manpower, BCA has been working closely with various institutes of higher learning (IHLs) to incorporate BIM training into more than 30 academic programmes. The agency's own educational institution, BCA Academy, and BIM vendors have also organised training for industry professionals.

Under the BCA BIM fund, incentives are offered to construction firms to adopt BIM. The fund, which is part of the Construction and Capability Fund (CPCF), covers the costs for training, consultancy services and purchase of hardware and software for businesses and projects.

It is suggested that the various initiatives have increased the level of adoption of BIM in the industry. According to a recent survey conducted by BCA, 65% of the industry has adopted BIM as compared to 20% two years earlier (Quek 2013).

FIELD STUDY

Empirical data were collected through face-to-face interviews and an online questionnaire-based survey.

Interviews

A series of face-to-face interviews was conducted from January to December 2014. The interviewees were 30 key people from 12 firms and institutions, which included six contractors, two architectural firms and one cost consultancy firm. There were also a representative from the government, and leaders of a professional institution and a trade association.

The interviews were intended to ascertain the current state of the industry's practice of BIM and productivity. This enabled the research team to develop the questionnaire for the much wider questionnaire-based survey.

The interviewees were asked to relate their views and concerns about the level of productivity in the construction industry in general, and the enablers and obstacles to productivity. They were also asked to share their views on the merits of, and challenges in, implementing BIM, and the potential of BIM to help in improving productivity.

Questionnaire survey

The questionnaire survey sought to ascertain how senior personnel in Singapore's construction industry perceive the current state of productivity and BIM in the industry, and the potential of BIM in improving productivity of the industry. A five-point Likert scale was used. The respondents were requested to indicate the level of effectiveness of, importance of, and necessity of, the various statements, as relevant. For example, when respondents were asked to rate their level of agreement with each of the statements on the obstacles to the use of BIM, they were required to select a number from 1 to 5, where 1 represented "*strongly agree*" and 5 stood for "*strongly disagree*".

Sampling

The respondents of the questionnaire-based survey can be classified into two groups: main contractors and consultants. The target population for main contractors comprised companies registered with the BCA under registration heads CW01 (general building) and CW02 (civil engineering). A total of 383 contractors were identified from the BCA Directory of Registered Contractors and Licensed Builders (BCA 2014a).

The consultants consisted of architects, structural and mechanical and electrical (M&E) engineers, and quantity surveyors. The interviewees were selected from the lists of members provided by the respective professional institutions in Singapore, which include the Singapore Institute of Architects (SIA), Association of Consulting Engineers Singapore (ACES) and Singapore Institute of Surveyors and Valuers (SISV). A total of 454 consultants were selected. Hence, the total number of target respondents is 837.

Responses

A total of 837 e-mail messages containing the links to the questionnaire survey were sent to the identified target respondents in August 2014. Some 55 e-mail messages bounced back because of wrong e-mail addresses. 59 usable responses were received, which reflected a response rate of 7.54 per cent (Table 1).

Table 1: Response rate

Respondents	Population	E-mail invitations sent out	Wrong e-mail addresses	Correct e-mail addresses	Usable responses	Response rate
Main contractors	2,709	383	22	361	25	6.93%
Architects	377	323	15	308	15	4.87%
Structural and M&E engineers	142	87	13	74	17	22.97%
Quantity surveyors	623	44	5	39	2	5.13%
	3,851	837	55	782	59	7.54%

Of the 59 firms in which the respondents were working, 34 were consultants. Of these, 12.00 per cent were architectural firms, 26.47 per cent were structural engineering firms, 14.71 per cent were M&E firms, 8.82 per cent were multi-disciplinary firms and 5.88 per cent were quantity surveying firms.

The respondents were those in the upper management level, such as managing directors, directors, partners and general managers (33.90 per cent), the middle management level, which comprised project managers, contracts managers, IT managers, BIM managers and architectural managers (32.20 per cent) and professionals, who included engineers, quantity surveyors, architects and BIM executives (33.90 per cent). It was made clear in the cover letter accompanying the questionnaire survey that the responses should reflect the views of their firms.

In terms of the degree of subcontracting, the majority of the contractors subcontracted a significant amount of their work. Forty per cent of the firms subcontracted 41 to 60 per cent of the value of their projects. Another 40 per cent subcontracted over 60 per cent of the value of their projects.

RESULTS AND DISCUSSIONS

Interviews

The general perception of the interviewees was that there has been some improvement in the productivity performance of the construction industry in Singapore. However, there was general concern among them about the shortage of skilled workers, BIM-trained personnel and architects. Many interviewees were also concerned with a low degree of skill retention, leading to low productivity. In particular, due to the current transient site workforce, the industry has to constantly train new people who mainly come from neighbouring countries. Hence, there is a lack of experienced supervisors, as well as a lack of commitment among the (transient) workforce.

The regulations force the contractors to change the way they work. For example, the buildability and constructability framework pushes the contractors to change their mindset towards precast and prefabrication.

The interviews also revealed that there is a lack of uniformity in the methods adopted for productivity measurement across the industry. The methods adopted generally follow the requirements specified by the clients or the authority. However, some companies have developed their own methods of measuring productivity. Examples include being based on schedule (number of months required to complete the project), cost (number of days worked per unit cost), structure (monitoring which construction method is faster) or earnings per month.

The interviews revealed that there are different levels of BIM utilisation since the industry is undergoing a transition period in terms of BIM utilisation. While some companies have achieved advanced levels in its application, some mainly use BIM for the compulsory submission.

The interviewees agreed that BIM brings about many benefits which will eventually improve productivity. BIM is a useful communication tool among the project participants, within the design team, and between consultants, contractors and clients. BIM may speed up the construction process since it allows all project participants to work simultaneously, minimises changes during construction, helps to eliminate a lot of construction errors and reduce rework.

The interviews revealed that the most common obstacles to BIM implementation are interface issues, legal issues, cost and time. Government incentives have been a great help for the companies; many of them have used up the maximum sum to which they are entitled to make the appropriate investment. More help and support, especially for subcontractors, is needed.

Questionnaire survey

The respondents were asked to express their views on the effectiveness of various measures in improving the productivity level of the construction industry in Singapore on a scale of 1-5 (1 being “*very effective*” and 5 being “*not effective at all*”). Table 2 shows that the incentives provided by the government such as the schemes for technology adoption (which includes BIM), incentive schemes for workforce training and upgrading and the Construction Engineering Capability Development Programme (CED Programme) are preferred. The CED Programme is an incentive scheme from the BCA for main contractors taking on complex construction projects. The scheme provides financial incentives for manpower development, engineering capability development and construction financing (BCA 2014b). Meanwhile, the industry gave

lower support to mandatory requirements such as the mandatory submission of buildability score, constructability score and productivity data.

Table 2: Measures that have improved the productivity level of the construction industry*

	N	Mean	Standard error	Standard deviation	Variance
Incentive schemes for technology adoption	55	2.11	0.141	1.048	1.099
Incentive schemes for workforce training and upgrading	55	2.22	0.144	1.066	1.137
Construction Engineering Capability Development Programme (CED Programme)	55	2.24	0.149	1.105	1.221
Mandatory submission of buildability score	55	2.76	0.168	1.247	1.554
Mandatory submission of constructability score	55	2.84	0.168	1.244	1.547
Mandatory submission of productivity data	55	2.93	0.162	1.200	1.439

* The measures were extracted from the Construction Productivity Roadmap (BCA 2011). Most of the respondents are familiar with the measures, as only 5 out of the 59 respondents selected "not aware" of the particular measure.

Next, the respondents were asked to indicate their agreement (or otherwise) with the obstacles to the use of BIM in their firms on a scale of 1-5 (1 being "strongly agree" and 5 being "strongly disagree"). Table 3 shows that the top three obstacles to the use of BIM as follows: difficulty in finding personnel competent in BIM; cost of implementation, excluding staff training; and cost of staff training. As discussed in the earlier section, the Singapore government has implemented some initiatives to help address the obstacles by organising training and giving incentives to construction firms to adopt BIM.

Table 3: Obstacles to the use of BIM*

	N	Mean	Standard error	Standard deviation	Variance
Difficulty in finding personnel competent in BIM	59	2.02	0.133	1.025	1.051
Cost of implementation, excluding staff training	59	2.15	0.162	1.243	1.545
Cost of staff training	59	2.20	0.147	1.126	1.268
Lack of support from clients	59	2.27	0.143	1.096	1.201
Inadequate incentives	59	2.31	0.137	1.055	1.112
Maintenance costs	59	2.37	0.153	1.173	1.376
Lack of clarity of government policies	59	2.61	0.151	1.160	1.345
Lack of direct benefit from implementation	59	2.61	0.147	1.130	1.276
Insufficient demand for the application of BIM	59	2.76	0.150	1.150	1.322

* The obstacles were extracted from literature review (Arayici et al. 2009, Smith and Tardif 2009, Gu and London 2010, Azhar 2011, Rajendran and Clarke 2011) which were confirmed by the findings from the interviews.

More than half of the firms cited co-ordination, submission, planning, clash detection and visualisation as the main reasons for using BIM (Table 4). The least mentioned reasons were facility management, sales and simulation of carbon emission. Most of the firms used BIM at the earlier stages of the projects (Table 5). As many as 45 firms use it at the design and pre-construction stage; while the degree of use lessened towards the end of the projects. Only eight firms use BIM at the post-construction

stage. Next, the respondents were asked to indicate their agreement with the potential of BIM on a scale of 1-5 (1 being “strongly agree” and 5 being “strongly disagree”). The first two potential uses and benefits indicated by the respondents were what BIM has been commonly known for: pre-project planning and identification of documentation errors (Table 6). The third potential was productivity monitoring using actual construction site data. The last three indications of BIM potential relate to utilising BIM for safety: safety monitoring, hazard identification and safety simulation.

Table 4: Reasons for the use of BIM

Reasons for the use of BIM	Number of firms	Percentage	Reasons for the use of BIM	Number of firms	Percentage
Coordination	44	74.58	Communication	16	27.12
Submission	40	67.80	Training	16	27.12
Planning	38	64.41	Prefabrication	15	25.42
Clash detection	33	55.93	Simulation of materials	10	16.95
Visualisation	32	54.24	Code reviews	8	13.56
Quantity take-off or cost estimation	25	42.37	Facility management	6	10.17
Project management	24	40.68	Sales	5	8.47
Sequencing	17	28.81	Simulation of carbon emission	3	5.08

Table 5: The stage at which BIM is used in the projects

The stage of which BIM is used in the projects	Number of firms	Percentage
Design and pre-construction stage	45	76.27%
Tender documentation stage	21	35.59%
Construction stage	30	50.85%
Post-construction stage	8	13.56%

Table 6: Potentials of BIM

	N	Mean	Std error	Std dev	Variance
Pre-project planning	59	1.97	0.130	0.999	0.999
Identification of documentation errors	59	2.29	0.130	1.001	1.002
Productivity monitoring using actual construction site data	59	2.37	0.151	1.158	1.341
Location tracking	59	2.51	0.140	1.073	1.151
Conformance to performance standards and regulations	59	2.51	0.122	0.935	0.875
Safety monitoring using actual construction site data	59	2.64	0.134	1.030	1.061
Hazard identification	59	2.66	0.140	1.077	1.159
Safety simulation	59	2.69	0.159	1.221	1.492

CONCLUDING REMARKS

The development and application of IT in the construction industry in Singapore has been broadened with the use of BIM as the platform to facilitate the integration of knowledge and information among the practitioners participating in construction projects.

Regulations have resulted in improvements in many aspects of construction in Singapore, and have been the main driver of BIM implementation. BCA and buildingSMART Singapore, have been launching a number of initiatives to promote the use of BIM in the industry in Singapore. Despite all the efforts, the findings from the study indicate that much more can be done in the effort to promote the use BIM at a higher level, and to explore to a greater extent the potential that BIM can offer. The respondents acknowledge that BIM has the potentials beyond the mandatory submission, through pre-project planning, identification of documentation errors and productivity monitoring using actual construction site data. However, many firms still use it only at the design and pre-construction stage. Very few of the firms use BIM at post construction stage and for facilities management. In future, further studies including a larger sample size such as facilities management firms and clients are necessary to clarify the findings.

In the long term, regulation alone will not be adequate; the construction industry needs to be more proactive. Several issues need to be resolved in order to exploit the potential of BIM in improving productivity to a greater extent. There is a need for holistic co-ordination among the industry's stakeholders including the government, industry, BIM vendors, clients and educational institutions. Many years into the implementation of BIM, the industry still face the same obstacles as encountered elsewhere (Arayici *et al.* 2009, Chien *et al.* 2014 and Murphy 2014). For example, as highlighted by the respondents of the questionnaire survey, the first obstacle is the difficulty in finding personnel competent in the usage of BIM. To address the shortage of BIM practitioners, the industry and academic institutions should work together to develop syllabuses that are in line with developments in industry practice and procedures. There should also be a system within each firm to ensure that the practitioners retain, actually apply and also share the knowledge gained from such programmes.

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BUILDING INFORMATION MODELLING ENERGY PERFORMANCE ASSESSMENT ON DOMESTIC DWELLINGS: A COMPARATIVE STUDY

John Spillane¹, David Stundon², James P. B. Lim³, Paul Tansey⁴ and Marc Tracey⁵

¹*School of Planning, Architecture and Civil Engineering, Queen's University Belfast, Belfast, Northern Ireland, UK*

²*William Hare Limited, UK*

³*Faculty of Engineering, University of Auckland, Auckland, New Zealand*

⁴*Ostick and Williams Architects, Belfast, Northern Ireland, UK*

⁵*Department of Civil Engineering and Construction, Institute of Technology Sligo, Sligo, Ireland*

Building Information Modelling (BIM) is growing in pace, not only in design and construction stages, but also in the analysis of facilities throughout their life cycle. With this continued growth and utilisation of the BIM processes, there comes the possibility to adopt such procedures to measure accurately the energy efficiency of buildings; and therefore, their energy usage. To this end, the aim of this research is to investigate if the introduction of BIM Energy Performance Assessment in the form of software analysis provides accurate results, when compared with actual energy consumption recorded. Through selective criterion sampling, three domestic case studies are scrutinised, with baseline figures taken from existing energy providers, the results scrutinised and compared with calculations provided from two separate BIM energy analysis software packages. Of the numerous software packages available, criterion sampling is used to select two of the most prominent platforms available on the market today. The two packages selected for scrutiny are Integrated Environmental Solutions - Virtual Environment (IES-VE) and Autodesk's Green Building Studio (GBS). The results indicate that IES-VE estimated the energy use in region of $\pm 8\%$ in two out of three case studies, while GBS estimated usage approximately $\pm 5\%$. The findings indicate that the introduction of BIM energy performance assessment, using proprietary software analysis, is a viable alternative to manual calculations of building energy use, mainly due to the accuracy and speed of assessing, even the most complex models. Given the surge in accurate and detailed BIM models and the importance placed on the continued monitoring and control of buildings energy use within today's environmentally conscious society, this provides an alternative means by which to assess accurately a buildings energy usage, in a quick and cost effective manner.

Keywords: building performance, green buildings, modelling.

INTRODUCTION

Building Information Modelling (BIM) is not a new process, having originated within the petrochemical sector under various aliases; but it was not until 1962 that Douglas C. Englebarts, in a report on 'Augmenting Human Intellect', that the phrase first emerged (Englebarts 1962). In the context of the built environment, the concept of

¹ j.spillane@qub.ac.uk

BIM began to gain traction through the emergence of visual representation and accompanying programming environment. However, it is only in the last ten to fifteen years that BIM has begun to thrive in the construction sector, mainly under the premise of increasing the collaborative working environment. With the United Kingdom (UK) Government mandate of April 2016 for stage two BIM implementation fast approaching, the construction industry is continuing to upskill and develop the necessary competencies and processes required to meet this directive.

BIM is documented as an essential tool for the integration and amalgamation of intelligent and informative models, based on underlying information, integrated within a common data environment. Azhar (2011) outlines numerous benefits, including increased collaboration, accurate modelling, and increased appreciation of the inherent design process. However, in the context of analysing existing structures, this ability has yet to be introduced and maximised within the construction sector in any meaningful manner. Interestingly, Laine *et al.* (2007) outline that there are benefits derived in thermal performance management in building design and suggest that this process should also include operation. Crosbie *et al.* (2010) also advocates energy profiling of both new and existing buildings, while Schlueter and Thesseling (2009) advocate energy performance assessment in early design stages. However, these and other researchers fail to consider addressing energy analysis, using case studies, to measure the actuality within the built environment, specifically in a domestic construction context.

To this end, the aim of the paper is to investigate, by using three individual domestic case studies, the accuracy of BIM Energy Performance Assessment in the form of software analysis, when compared with actual energy consumption recorded. The research design applied in this instance is founded on the analytical review of three case studies using a variety of software packages. The results will help to identify the most accurate form of energy performance assessment method; thus helping practitioners in their selection and application of energy assessment, both in design and maintenance. It will also aid an academic audience in the appreciation and importance of accurate energy performance assessment, while also spurring additional research streams within the subject in context.

BUILDING INFORMATION MODELLING AND ENERGY ANALYSIS IN BUILDINGS

Since the introduction of ‘Our Common Future’ and the idea of sustainability, many of the world’s governments have begun placing sustainability targets on its industries. The European Union legislative body introduced these targets and regulations in an attempt to limit the allowable energy consumption of buildings (Department of Communications 2009). This creates performance based building energy targets, which have resulted in clients and the architectural, engineering and construction sectors working together, to create carbon efficiency in the built environment. To facilitate this, technology has been developed and adapted to ensure that the targets for energy savings and carbon dioxide emissions can be achieved through efficiency in building design (Motawa and Carter 2012).

With this technological development, BIM has emerged as one of the leading processes in which to assist in monitoring and controlling these energy consumption concerns. BIM is a digitally constructed representation of a building’s design using intelligent and intuitive design founded on component construction. This digital representation, not only allows for 3D visualisation, but also incorporates a vast array

of intellectual information, including precise building geometry, spatial attributes and, most importantly, element thermal properties; all of which is intended to support the stages of the project from design through to operation and decommissioning (Azhar 2011).

Azhar *et al.* (2011) suggest that BIM is fully capable of enhancing a buildings sustainability, but to date, this ability has yet to be maximised by the construction sector. As such, BIM has developed analytical support systems, which enable users to carry out energy efficiency analysis, of both new and existing buildings (Ryan and Sanquist 2012). This type of analysis is produced under the remit of the sixth dimension (6D), which is what is commonly referred to as the sustainability and life cycle dimension; thus forming part of the facilities management aspect within the overarching BIM process. Using BIM, even in this regard, has the potential to result in faster and more effective processes, controlled whole life costs and energy data, integrated planning and implementation; thus leading to a more competitive industry with long term sustainable growth and ultimately, better customer service (Arayici 2008).

As a tool for assessments, Krygiel and Nies (2008) suggests that BIM Energy Performance Assessment, which is also known as Energy Profiling, can be used to perform part of the life cycle analysis, by measuring and predicting building energy use, in both late design and operational phases. Ultimately, this mode of energy use assessment must be as accurate as possible, in order to produce reliable and usable results for the sector. According to Crosbie *et al.* (2010), energy performance assessment or energy profiling, typically involves the analysis of a buildings actual energy performance. This will ideally lead to the improvement of the energy performance of buildings through more informed design. Therefore, this energy performance assessment can potentially be applied as a more efficient and accurate alternative for manual calculations and associated assessment. The use of current manual calculations is partly driven by legislative pressure; a premise supported by Crosbie *et al.* (2010), who suggests that increasing energy prices and legislative regulations are causing a surge in interest in energy performance assessment, in both the commercial and domestic sector. Energy performance assessment can typically be applied in two phases; either individually or collectively. In the context of the design phase, this involves the building designers running energy simulations to analyse the buildings energy performance. Under the operational phase, assessment is based on actual energy consumption within the building and the results used to illustrate how building owners can improve their energy usage (Hellingsworth *et al.* 2002; Crosbie *et al.* 2010). With the continuing advancement of BIM being used for design stage energy profiling (Crosbie, *et al.*, 2010), it is conceivable that it can be used for operational stage profiling. To date, this is only considered and incorporated within building management systems in the context of facilities management, with the merits of its application to existing buildings for energy use estimation, yet to be widely tested.

To this end, it is estimated that the overall effective use of BIM, specifically in the context of this paper, can be achieved through the integration of 'tested' simulation tools to improve accuracy of the simulations (O'Donnell *et al.* 2005; Krygiel and Nies 2008). Stadel *et al.* (2011) emphasise that BIM can be used for this purpose, as the parent modelling software in some cases, has convenient plug-ins, to calculate operational energy usage. The use of such an approach is further supported by Motawa and Carter (2012), who specified, that for energy analysis to be accurate, one

must use the integrated energy analysis software available within the BIM design packages used.

It is conceivable that with the advancement of technology, BIM can assist in the establishment of higher standards of excellence in the future. This advancement could potentially aid in the achievement of the government targets and building regulations set out under BIM 2016 (Bynum *et al.*, 2013). Bynum *et al.* (2013) also propose that through sustainable business practice, such as willingness to co-operate to achieve maximum collaboration, BIM will be maximised, and thus, it is conceivable that this will result in more efficient BIM operation and furthermore, a potential for highly accurate energy analyses.

However, Crosbie *et al.* (2010) and Motawa *et al.* (2012) criticise its use in this fashion, as they believe that the current energy analysis software applications available through BIM, are based on estimated values and assumptions of operational use, much like the manual energy performance assessment techniques. This in turn, has the potential to result in inaccurate energy use estimates. Ryan and Sanquist (2012), found that the largely unpredictable nature of occupancy could result in errors and thus, produce inaccurate data. Subsequently, research by these and other practitioners demonstrate that the accuracy of building energy profiling software may not be accurate in every instance. As a result, and for the purposes of this study, the accuracy in a domestic context must be determined, in order for both the industry and academic sectors to ascertain the future value within this practice.

RESEARCH DESIGN

In order to address the aim of investigating the accuracy of BIM Energy Performance Assessment in a domestic context, it is essential to, firstly, identify potential case studies to measure the actual performance of modelled structures and secondly, to identify potential software packages to utilise as part of the review process.

Firstly, in the context of the case studies identification and selection process, in order to minimise interoperability issues when exporting models into the respective energy analysis software, a relatively simple structure is selected - a domestic building. Ten case studies are identified based on adopting a criterion sampling method, where the properties in question have to meet a set of predetermined conditions. Firstly and most importantly, each case study must be a domestic, detached unit. Additionally, each of the case studies must have the consent of the homeowner, have access to at least twelve months of utility bills and have access to the premises to survey the respective buildings to assist the modelling of the structures. Of the ten potential case studies identified using this method, random sampling is then introduced to shortlist and ascertain three random case studies for inclusion in the research. This process reduces the possibility of researcher bias in the identification and selection of the case studies for inclusion in the research. Additionally, through triangulation of the case study data, it is possible to identify and document trends that are beyond chance alone. Subsequently, three domestic dwellings are selected; case study I is a detached single storey dwelling built in the late 1940's / early 1950's, case study II is a two storey semi-detached dwelling built in the late 1970's / early 1980's, and case study III is a detached two storey dwelling built in 2005.

Each of these structures is surveyed and modelled using Autodesk Revit. This software package is selected as it allows for structured creation of the models while also having the capability to incorporate occupancy and energy usage data through its

MEP (Mechanical, Electrical and Plumbing) provisions. This software platform also supports the export of gbXML format, which is supported by most energy analysis software packages. Finally, this software also accommodates supporting add-on capability with the selected energy analysis software, which further mitigates the potential for interoperability issues to emerge during the transfer and examination of the respective structures.

Secondly, with regard to the analytical software packages considered for this study, both Integrated Environmental Solutions – Virtual Environment or IES-VE and Autodesk's Green Building Studio or GBS, utilising the default analysis in both cases, are shortlisted for consideration. Both packages are selected due to their integrated functionality with Autodesk Revit, while providing functionality that will simulate and assess the energy requirements of each of the nominated dwellings. Originally, a third option in the form of Autodesk Ecotect Analysis is considered; however, it is intended to be used in conjunction with GBS to provide additional functionality. This additional functionality is not required for the current study; therefore Autodesk Ecotect was omitted from the study.

To ensure consistency within the research and supporting analysis, each case study follows a specific vein, as detailed in Figure 1.

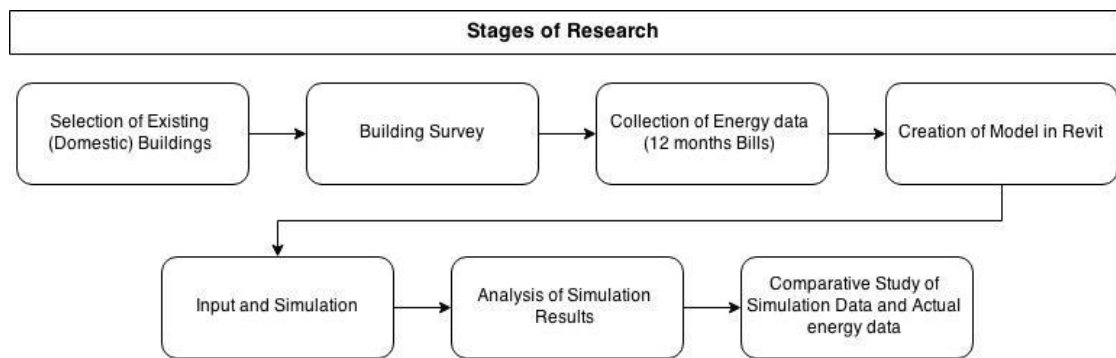


Figure 8: Research Flow Chart

Once each of the three case studies are modelled and analysed using the respective tools identified, the results are quantified using an energy comparison spreadsheet. This spreadsheet is created to compare and contrast the results and calculate percentage differences, in each case, while also comparing the results against the baseline. The baseline is calculated from the existing utility bills from each of the respective domestic units; thus providing an insight into the actuality of the case studies in question. This then provides the ability to establish a percentage difference between the results compared and recorded to the baseline energy use acquired from the existing energy bills from the respective dwellings. Given that a percentage is used to establish the accuracy of the models and their underlying energy outputs, a margin of error is applied. In light of this, previous research by Maamari *et al.* (2006) and Reeves *et al.* (2012) highlight that computer simulations are deemed accurate where results are produced within $\pm 15\%$ of the control test. Therefore, in the context of this paper, results that emerge within this range of the existing baseline are deemed accurate.

RESULTS AND ANALYSIS

As outlined, three case studies are carried out, detailing the baseline energy use over an eighteen-month period and the two BIM Energy Performance Assessment

simulations results compared. The result of the analysis is displayed in table 1. Given the results, particularly in case study I, it would appear that the simulations proved promising. However, geometrical issues are encountered in the attic space of case study II, which prevented the simulation from being carried out until that space was removed. This issue is encountered in GBS, and therefore the results produced by GBS in this instance are based on the building minus one bedroom. In light of this, the results from case study II are not considered appropriate and as a result, are omitted from the study. Further detailed research is ongoing at the time of writing, where this anomaly is revisited and contingency measures introduced to eliminate this issue within the analysis.

Table 1: Case study analysis results

Case Study 1



Case study 1 results

	Total kWh
Baseline	19,928.61
GBS	13,953.50
IES	15,380.00

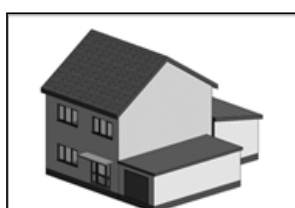
Case study 1 - % difference

	% Difference
Baseline	0%
GBS	-30%
IES	-23%

Case 1 - Heating & Electrical %

	Heating	Electrical
Baseline	-	-
GBS	-29%	-33%
IES	-8%	-93%

Case Study 2



Case study 2 results

	Total kWh
Baseline	16,916.55
GBS	17,313.33
IES	17,809.80

Case study 2 - % difference

	% Difference
Baseline	-
GBS	2%
IES	5%

Case 2 - Heating & Electrical % Difference

	Heating	Electrical
Baseline	-	-
GBS	-5%	15%
IES	52%	-73%

Case Study 3



Case study 3 results

	Total kWh
Baseline	21,539.46
GBS	34,904.11
IES	30,369.70

Case study 3 - % difference

	% Difference
Baseline	-
GBS	62%
IES	41%

Case 3 - Heating & Electrical % Difference

	Heating	Electrical
Baseline	-	-
GBS	28%	171%
IES	8%	145%

COMPARATIVE DISCUSSION

Based on the results outlined in Figure 1, in the majority of cases, all estimates are far beyond the acceptable $\pm 15\%$ percentage difference prescribed to ascertain that the results are accurate when compared with existing utility bills. Following the breakdown of the data, it is determined the reason for the widely varying estimates is due to the lack of electrical appliance data. This could have been achieved through accurate input of Watts (W) or Kilowatts (kW) used by the total number of appliances in a dwelling, that is, televisions, washing machines, etc. Therefore, the result produced by GBS, where electricity is estimated within the acceptable percentage

difference at 15%, is not considered valid, as the electrical appliance data and its use is not known.

Despite these issues, it is determined that, due to the wide variation of the electrical data, no viable conclusion could be achieved. Therefore, the electrical estimations have to be omitted from the overall results of the study. Regardless of these findings, the remaining heating energy category still presented practical results as shown in table 2. The results from the electrical data are to be revisited and deliberated further in an alternative piece of research, focusing on electrical energy performance measurement. Once the data relating to the electrical aspects are revisited, the results will be subsequently published in a paper and subsequent separate study focusing on this aspect of the research. However, this does not affect the results relating to heating, as in all of the case studies herein, heating is provided by means of solid fuel, oil or gas. Therefore, the results relating to heating are both relevant and accurate.

Table 2: Percentage differences in heating results of case studies

	Case Study I	Case Study II	Case Study III
Baseline	-	-	-
IES	-8%	52%	8%
GBS	-29%	-5%	28%

It is determined that the heating estimation and simulation results produced by GBS are outside the acceptable $\pm 15\%$ in two of the three case studies (+28% and -29%). However in the context of IES-VE, in two of the three case studies, the simulation presented promising results of -8% and +8% respectively, with only one beyond the acceptable threshold (+52%).

CONCLUSION

With the emergence of BIM throughout the construction sector, in conjunction with the need to take more effective control of our built environment energy usage, there is a need to link these aspects collectively. The literature clearly illustrates the need for greater energy efficiency driven by government targets (Department of Communications, Energy and Natural Resources, 2014; Bynum, *et al.*, 2013; Hellingsworth, *et al.*, 2002). Additionally, clear evidence is provided to demonstrate that BIM could aid this need for greater energy efficiency through BIM Energy Performance Assessment capability.

To address this dearth in knowledge and application in context, an initial case study analysis of three domestic units is undertaken using Integrated Environmental Solutions – Virtual Environment (IES-VE) and Autodesk's Green Building Studio (GBS) with the models produced in Autodesk Revit. The study confirms the accuracy of one of the BIM Energy Performance Assessment tools, by comparing the estimated annual energy data produced by GBS and IES-VE in comparison to the calculated baseline use. In this context, the BIM Energy Performance Assessment tools are considered accurate, only if they meet the percentage difference criteria of within $\pm 15\%$ (Maamari *et al.* 2006). Through the use of three case studies it can be confirmed that one of the two BIM tools is accurate in the majority of cases (two from three instances measured) in terms of heating prediction. However, even though the estimates could be construed as accurate overall, when they are broken down, the values merely averaged out to obtain a random estimate that was only accurate by chance. The study concludes that IES-VE is the more accurate of the two BIM

assessment tools surveyed. The results produced by IES-VE in terms of heating estimations, can be confirmed accurate in two instances (case studies I and III).

It is found that, in the majority of cases, the electrical estimates through IES-VE and GBS are all either significantly over or underestimated (>15%), as a result of insufficient electrical appliance data. Therefore, this data is not included in the comparison. This also suggests that BIM Energy Performance Assessment may not be sufficiently robust to provide overall energy estimates for domestic dwellings, as it may not be possible to accurately estimate both the potential number and energy use of the electrical appliances in the building. This indicates that using BIM Energy Performance Assessment in isolation may not be feasible without considering the inclusion of appliances within the design. Therefore, for the purpose of this paper, the electrical data is not considered nor discussed in detail, but the subject of further investigation, with the emphasis on the heating data and the results provided. In relation to the results reported on heating, these figures remain unaffected, as heating in all of the case studies is provided outside of electrical means.

Furthermore, this is combined with the variable nature of occupancy schedules in different rooms of the building, which may not be possible to accurately predict (Ryan and Sanquist 2012). Due to this, further research is ongoing on the aspect of obtaining more complete data using a larger sample size and more detailed modelling techniques, to mitigate such anomalies within the dataset. This includes the acquisition and inclusion of further case studies including various domestic dwellings beyond detached units, to address the limitations that are evident in the selection of a single domestic style.

However, despite this, when all heating estimation values and percentage differences of both the simulation results and measured data are compared, it concludes that IES-VE is the more accurate heating energy estimation method for these domestic buildings, when compared with GBS. These findings can be used by those designing and working within the context of domestic construction sector, to assist in making informative decisions; however, due to the preliminary nature of the study, it is not possible to conclude by stating that the results herein should be adopted without question, but simply provide another level of scrutiny in the energy performance assessment measures adopted.

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MAJOR PROJECT TEAM LEARNING: EXAMINING BUILDING INFORMATION MODELLING

Edward Simpson¹, Daniel Gilmour, David Blackwood, Ruth Falconer and John Isaacs

School of Science, Engineering and Technology, Abertay University, Dundee, UK

The speed of technological advancement of software development drives the need for individual and team learning to exploit these developments for competitive advantage. Using a major long term redevelopment as a case study a review of learning processes and project team learning in the context of a voluntary approach to adopting of BIM prior to 2016 is examined. The speed of adoption of BIM across a large redevelopment project covering several years is variable and the differences of preparedness between team members from different organisations raises the question of how effective the project team can be in sharing learning and increasing the speed of adoption of BIM. The benefits of understanding the project environment as a formal learning context are recognised where teams are working in partnering arrangements but the focus is usually on post project review of what went wrong with little time to critically evaluate other variables. Knowledge Management has the potential to help understand and then facilitate greater participation amongst stakeholders in project team learning. The research team undertook decision mapping and knowledge elicitation techniques and applied these to the Dundee Waterfront to identify key factors relevant to successful project management, enabling the Waterfront Project Team to understand current practice. The effectiveness of project team learning in relation to BIM within this long-term major redevelopment is influenced by positive motivational drivers for individuals to learn how to use and apply BIM, the level of organisational support for learning and professional development and the project information and communication systems. In practice the current approach to sharing of knowledge within the project team indicates a fragmented approach in relation to the adoption and application of BIM to managing construction projects.

Keywords: individual learning, knowledge management, team learning.

INTRODUCTION

The construction industry is experiencing the impact of rapid technological developments in relation to both design and construction processes that demands continuous learning of the design team. Can project teams learn sufficiently quickly to keep up with the pace of change effectively and efficiently? The larger the project team and the longer the project then the more important it is to understand the complexities of how large multi-disciplinary teams can work towards sustained team performance through knowledge and skill development. Bunderson (2003) ascertained that it was essential to have a balance between learning and overall team goals for effective team performance but teams that over-emphasise learning may compromise their performance (Levinthal and March, 1993). Using the focus of the

¹ e.simpson@abertay.ac.uk

adoption of BIM within a large, multi-disciplinary waterfront redevelopment project the research team investigated team learning and assessed the impact in relation to project team knowledge development.

INDIVIDUAL LEARNING THEORY

The importance of learning is recognised by professionals in their individual roles within the construction process and by organisations as a part of maintaining competitive advantage (Bhargav and Koskela 2009). In each case a successful learning context was found where the individuals were personally motivated to succeed, could identify the appropriate opportunities and provided with the necessary resources (Seward 1952). The ability of individuals within a team to perform familiar tasks in more efficient ways and facilitate novel problem solving in an ever-changing environment contributed further to an individual's knowledge base (Rumbaugh *et al* 2012) and that of the team if it was shared within the team environment.

Priorities for organisational support for learning are affected by factors such as organisational strategy, in this case for engaging with BIM, requiring the development of knowledge through assessing the appropriate software and where it can be applied for effective results within an organisation, assessing the consequences and making subsequent improvements. Where the motivation for learning is not driven by a positive personal desire (a pull factor) but by fear of consequence for failing to adapt to change (a push factor) individual motivation towards learning is adversely affected. In this situation individual motivation will be present, but the approach-avoidance to learning to BIM will be adopted (Madan, 2013), indicating that whilst organisational objectives may be achieved the issue of successful learning that can be shared within teams could be limited.

There are different theories to explain individual learning (Pashler 2008), but within the context of a major project team Kolb's Experiential Learning model provides an appropriate model for explaining the learning processes of individuals, teams and organizations. Experiential Learning Theory as a structured approach to team learning has been shown to be successful in helping teams to develop the essential competencies necessary for team learning (Kayes 2005). Kolb and Kolb (2005) have demonstrated that knowledge is derived from two actions; requiring understanding which is described as 'grasping experience' and application which is described as 'transforming experience'. In examining the context of team learning it is necessary to identify the actions, events, behaviours and decision making processes that an effective team exhibits (Day, Gronn and Salasc, 2004).

PROJECT TEAM LEARNING

Carrillo (2005) identifies the exploitation lessons learnt and experiences to improve performance on future projects, is highly desirable to construction companies offering commercial success. However, a project based industry involving multiple stakeholders and complexity provides a challenge where project memory is not integrated in to organisational memory (Ghosh *et al* 2012). Teams are complex, dynamic, and adaptive systems (McGrath, Arrow, and Berdahl, 2000) bounded by context and time variables (Ilgen *et al.* 2005). Hannes *et al.* (2013) reviewed team learning and ascertained that employees learn for different reasons and in different ways, identifying three factors required to facilitate team learning:

- Effective open multi-disciplinary communication

- Minimising power inequalities that flow from hierarchical differences within team relationships
- Stimulating commitment and devotion towards team learning, and to consider the place of reflection and action in this process

There is a hierarchy of learning, commencing with individual learning, then team learning with organisational learning (Figure 1). Research into the complexities of team learning is focused on intra-organisational teams with the result that there is limited research into how inter-organisational multi-disciplinary teams such as major construction project teams learn and share knowledge. Whilst individual and team learning is identifiable within organisations, the construction project team adds another layer of complexity to the learning process (Figure 1). Typical construction project teams involve cross-discipline working and another team context overlapping with different organisational, team learning and individual learning processes. While professionals are happy to share knowledge and learning from training and CPD events, where this knowledge has commercial value it was found there was some reluctance to share other than that absolutely necessary for operational reasons.

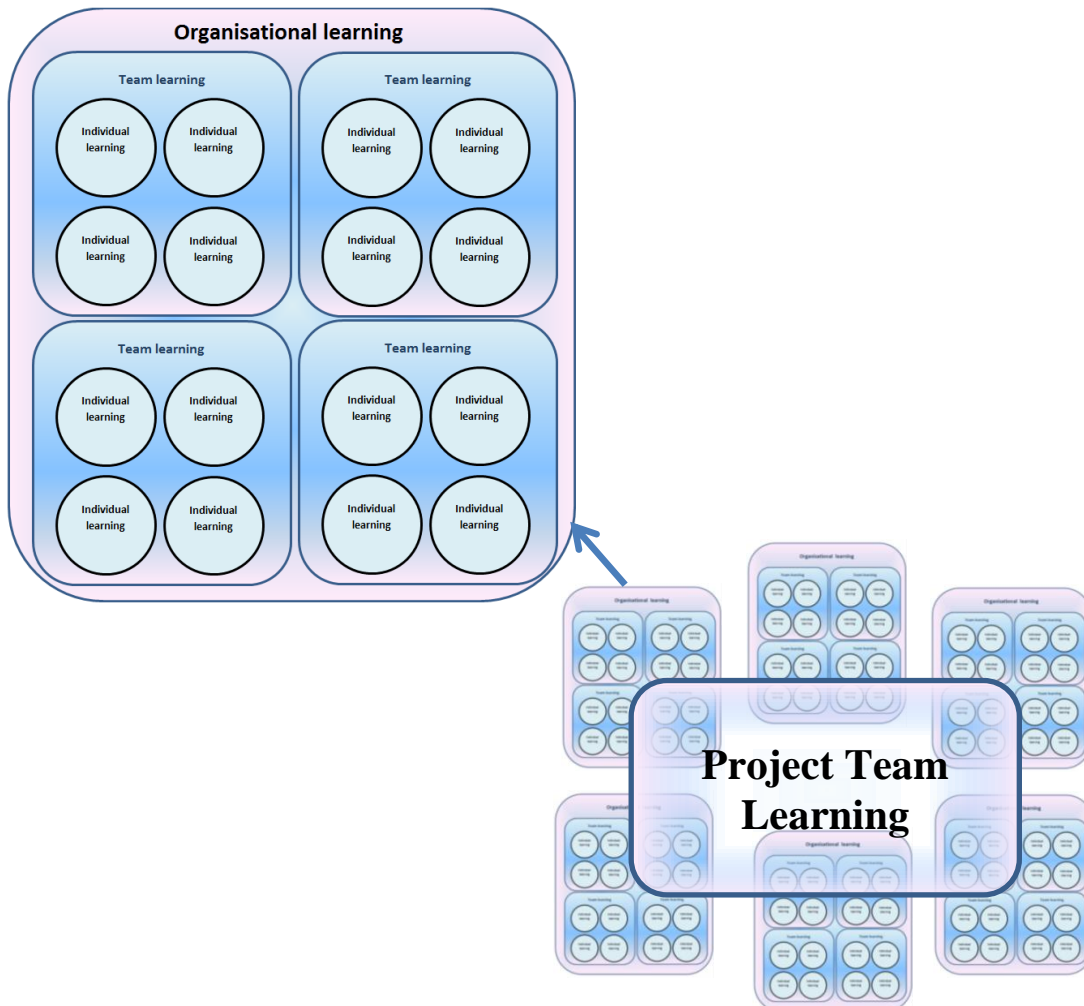


Figure 1: Project team learning

This multi-disciplinary and inter-organisational level of team learning is an additional level of complexity to organisational learning but important for corporate memory (Fruchter and Demian, 2002). For example, specialist mechanical and electrical sub-contractors with the ability to use BIM will do so but they indicate that there are limited benefits to sharing this knowledge outwith the organisation beyond operational requirements.

METHODOLOGY

Mapping Organisation Current Practice

Decision mapping and knowledge elicitation techniques were developed and applied to the Dundee Waterfront to identify key factors relevant to successful project management, enabling the Waterfront Project Team to understand current practice. A number of authors have effectively used decision mapping or knowledge mapping to document, understand organisation knowledge management and decision making (Snowden 2000; Driessen 2007; Yasin and Egbu 2010). The knowledge elicitation and mapping methodology utilised a combination of techniques drawn from the information technology, knowledge management and business process mapping fields. The detailed knowledge elicitation and process mapping methodology to identify and classify knowledge and identify Knowledge Disclosure Points has been reported previously in Gilmour *et al.* (2013)

In this study an Organic Knowledge Management approach (Snowden 2000) was adopted to elicit and categorise knowledge. This approach recognises that one cannot map knowledge without understanding of the process (Egbu 2006; Yoo 2007). Snowden (2000) terms these as Knowledge Disclosure points (KPDs) such as decisions, judgements, problem resolution or learning. The process mapping concepts have been used, together with Snowden's Organic Knowledge Management linguistic framework, to develop a technique which allows the Knowledge Disclosure Points to be identified during each process of all stages in infrastructure development.

Mapping was undertaken by interviewing key individuals responsible for a task or process. These individuals are termed 'process owners' and have a deep understanding of the phase of infrastructure or process under investigation. Process Maps were developed with the process owners during the interviews which were tape recorded for accuracy of the records. Maps were developed and subsequently verified through a series of interviews with each participant. Each of the interviews built up a set of process maps and associated Knowledge Objects based on Knowledge Disclosure Points.

The outputs of 12 interviews provided an understanding of the flow of information between the Waterfront Team and the City Engineer which is not only important in reporting and approvals but also for sharing knowledge and project learning. The interviews identified that project feedback, design reviews and experience sharing are ways where project learning is activated. The monitoring and reporting of sustainability provides the mechanism for project learning through KPI and Benchmark Indicators. These indicators feed into contract KPI and Service plan KPI at divisional level. They also feed into the Environmental Management System for the division. Experience is shared between team members but also with the City Engineer who has an understanding across all contracts and activities at the divisional level. The project learning process is illustrated together with the sustainability knowledge flow through project and management and reporting structure in Figure 2.

The findings of the mapping supports the literature in relation to the potential for knowledge management to demonstrate current practice, improve decision making and support sustainability enhancement. The wider implications of the findings of knowledge map can be related to the current work that emphasises the requirement for an effective mechanism to manage and reuse the knowledge created in projects such as discussed in Tan *et al.* (2012) and Leblanc and Thompson (2012). The case study has also illustrated the use of knowledge management in accelerating learning to develop expertise and improve processes affecting planning and design development, construction and operational aspects as discussed in work by Robinson *et al.* (2011).

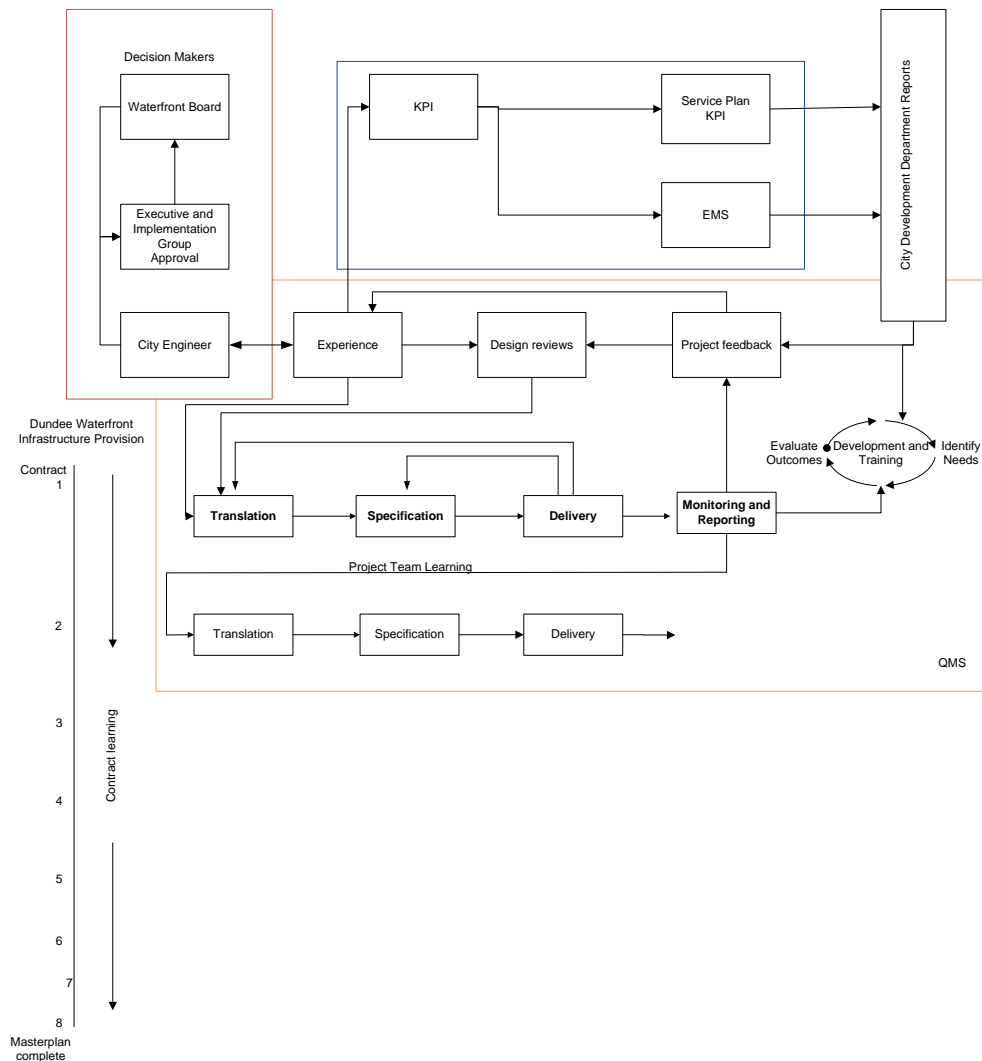


Figure 2: Project learning process of a major long term development

Contractor Interviews

Six further interviews were undertaken to establish the experience of design team participants contractors and subcontractors in relation to developing their BIM knowledge and skills. The team used thematic analysis (Braun and Clarke 2006) as a method for identifying, analysing, and reporting patterns (themes) within data based on a sample of semi-structured interviews covering an experienced client rep; an experienced contract manager with responsibility for contracts across Scotland for a large contractor, a very experienced project manager who is close to retirement, a groundworks sub-contractor, and two different mechanical and electrical sub-contractors. The main themes identified during the interviews are shown in Table 1.

Table 1: Themes

	Individual benefits	Organisational benefits	Influence other team members	Uncertainty
Client rep	X	X		X
Contract Manager	X	X		X
Project Manager		X		X
Groundworks SC	X	X		X
M&E SC 1	X	X	X	X
M&E SC 2	X		X	X

RESULTS

The theme of individual benefit through continuous learning and career development was recognised by the professionals interviewed and by organisations within their staff development processes as a part of maintaining competitive advantage, confirming previous studies (Bhargav and Koskela 2009). Due to the fragmented nature of the industry and the nature of project team formation with each unique construction project creating knowledge for individuals any knowledge, even explicit knowledge, does not automatically transfer to future projects. Information and communication technologies offer potential solutions (Bhargav and Koskela 2009; Ruikar *et al.* 2007) and the thematic analysis results identified expectations that BIM can provide organisations with a partial solution to capturing explicit project knowledge with the potential to access tacit knowledge as a project develops (Zhao *et al.* 2013), indicating that tools used to capture corporate memory such as BIM may be effective (Demian and Fruchter, 2006). Ho, Tserng and Jan (2013) proposed a BIM-based Knowledge Sharing Management (BIMKSM) system for project managers and engineers that they applied in Taiwan. Their research identified a number of limitations within their single case study, including the time required to extract and codify knowledge within the model and the inability to keep the model updated. Lin (2014) also identified BIM within a case study as having the potential to capture tacit knowledge with similar results. A common feature of both studies was that mechanical, electrical and plumbing design engineers demonstrated a leading role in sharing their use and knowledge of BIM. This was replicated within the Dundee Waterfront at this time with BIM being used by the mechanical, electrical and plumbing design engineers, having a positive impact on the projects within which they work and engaging others with their practice in relation to, for example, clash detection. Such evidence reinforces the assertion that project team learning will be successful in making more tacit knowledge visible in practical situations where BIM can be applied throughout the entire team.

The individuals and the knowledge they create are critical features for improving business performance and ultimately for collective learning; organisational culture, the application of technology and leadership are the three most important factors for influencing the success of Knowledge Management (Loforte Ribeiro 2009). Whilst Knowledge Management is important in the construction industry there is an unrecognised gap between rhetoric and reality in relation to expectations of technology (Esmi and Ennals 2009). This may be partially explained by the fact that

the culture of the construction industry is still predisposed to providing protection of knowledge (Keeble Kululanga 2009) and this creates uncertainty in relation to level of involvement and knowledge sharing with others as well as their organisation. Knowledge Management is not only a technical problem but a socio-cultural problem involving motivating people to make them willing to give up knowledge for organisational or project use (Robinson *et al.* 2005).

Using a Communities of Practice (CoPs) approach through BIM, project participants and engineers have the opportunity to get an overview of available knowledge in core project areas and take appropriate management in tacit and explicit knowledge (Lin and Lee 2012). CoPs are intra-organisational and an investigation of 57 CoPs from major European and US organisations identified the factors affecting success and failure in relation to sharing of knowledge (Probst and Borzilla 2008). The failure factors can explain why it is so difficult for a project team to achieve shared learning. The relevant failure factors included the low level of one-to-one interaction between team members and, where members trust their own competences they can be less willing to integrate practices originating from other CoP members into their daily work. These are typical features of the large waterfront redevelopment project. Project leaders have to deal with the challenges presented by the fast pace of not just organisational change but the project environment requiring skills to help them and their teams to interact more from shared experience emerging out of collective engagement (Vince 1998).

The difficulty for the Dundee Waterfront Redevelopment is that not all project participants or organisations are currently using BIM. Construction project teams do not transfer team learning to the organisational level as a collective body because the construction project team setting does not facilitate such a formal relationship between the project team and the organisation (Seneratne and Malewana 2011). There are examples, within the Dundee Waterfront Redevelopment where members of the client organisation, a major mechanical and electrical contractor and some contractors have experience and are currently using BIM, the adoption is for each organisation's own benefits. In examining the reasons why the mechanical and electrical contractor is taking a lead in BIM it became evident that this international organisation had a strategy of adopting BIM and had internal case studies demonstrating the benefits to the organisation of using BIM where possible. This specialist contractor had identified sound commercial reasons for adopting BIM where possible irrespective of contractual requirements. Until contractual requirements for all the team organisations to engage with BIM are in place the project team is currently limited to no more than a fragmented approach to shared learning on BIM as shown in Figure 3.

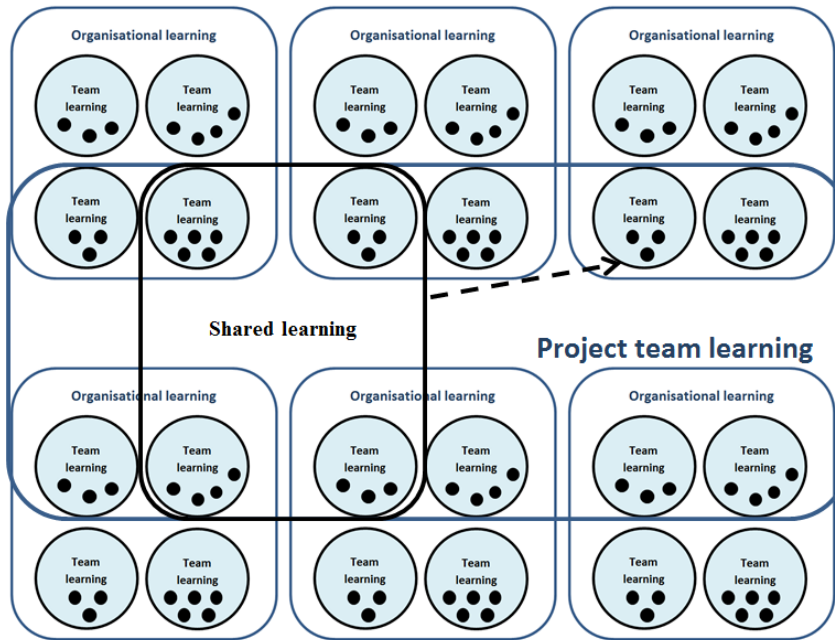


Figure 3: Fragmented project team learning

CONCLUSIONS

Project team learning is a complex process involving the interaction of numerous factors influencing individual learning, team learning and organisational learning. Capturing explicit knowledge is considered achievable through recognised organisational processes and procedures; capturing tacit knowledge has proven to be elusive although there is evidence that BIM may be one approach to address this issue. Knowledge Management has the potential to help understand and then facilitate greater participation amongst stakeholders in project team learning. The research team undertook decision mapping and knowledge elicitation techniques and applied these to the Dundee Waterfront and knowledge mapping techniques successfully identified current practice. The effectiveness of project team learning in relation to BIM within this long-term major redevelopment is influenced by positive motivational drivers for individuals to learn how to use and apply BIM, the level of organisational support for learning and professional development and the project information and communication systems. In practice the current approach to sharing of knowledge within the project team indicates a fragmented approach in relation to the adoption and application of BIM to managing construction projects. Within large project teams with constantly changing participants the adoption of BIM within the Dundee Waterfront redevelopment has had limited impact on encouraging learning of BIM across the project team. At the current time, where choice permits, those organisations leading the use of BIM have identified commercial benefits and are encouraged in the adoption and use of BIM by strategies for developing the individual skills and knowledge of their staff with the intent of providing the organisation some competitive advantage.

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BUILDING INFORMATION MODELLING (BIM) WITHIN THE AUSTRALIAN CONSTRUCTION RELATED SMALL AND MEDIUM SIZED ENTERPRISES: AWARENESS, PRACTICES AND DRIVERS

Callum Rodgers¹, M. Reza Hosseini², Nicholas Chileshe³ and Raufdeen Rameezdeen⁴,

^{1,3,4} *School of Natural and Built Environments, University of South Australia, South Australia, Australia*

² *School of Architecture and Built Environments, Deakin University, Victoria, Australia*

Review of literature on BIM reveals a bias towards focusing on large companies and overlooking SMEs in Australia. To bridge this gap of knowledge, this study explores the level of awareness, practices and drivers of BIM among SMEs within the Australian construction industry through the lenses of theories of innovation diffusion in construction companies. In so doing, a questionnaire survey was administered and 41 responses received from these SMEs engaged in commercial, industrial and public works. Accordingly, seven face-to-face interviews were conducted to compensate for the small sample size and to expand the survey data in more depth. The findings brought to light that current knowledge of BIM in SMEs is one-sided and negatively biased with a tendency towards highlighting challenges and overlooking the advantages. Besides, a significant association was spotted between the awareness of values of BIM and the practices related with BIM in SMEs. Additionally, the most influential drivers for BIM were turned out to be all associated with economic gains for the business of the companies alongside clients' demands. Furthermore, it was revealed that practices associated with BIM and awareness of BIM are similar across different sizes of SMEs.

Keywords: building information modelling, SMEs, drivers, innovation, Australia.

INTRODUCTION

BIM implementation is around 20% lower in Australia compared to North America (Stanley and Thurnell, 2014). On the other hand, the construction industry in Australia is dominated by SMEs which make up about 98% of all construction businesses and have the largest portion of total income (ABS, 2013). It is estimated that around 94% of firms in the Australian construction industry have fewer than 4 employees and only 0.5% of companies around Australia have employed more than 13 people (Mills *et al.*, 2012). This brings to light the profound positive impacts envisaged for promoting BIM within SMEs in the construction industry given the large amount of SMEs that are engaged within the construction supply chain as pointed out by Poirier *et al.* (2015). BIM is hitherto regarded as a technological innovation for construction

¹ rodcg001@mymail.unisa.edu.au

organisations (Poirier *et al.*, 2015). In this respect, evidence demonstrates that SMEs treat innovations in glaringly different ways in comparison to large-sized companies (Sexton and Barrett, 2003). As acknowledged by McGraw-Hill (2014) “...those not engaged with BIM tend to be smaller companies.” As asserted by Sexton and Barrett (2003) “this difference must be understood, and underpin policy and corporate guidance.” Yet, understanding any innovation within a certain context such as SMEs in Australia requires deployment of innovation diffusion models as urged by Poirier *et al.* (2015). That is, grounding any context-oriented study in innovation diffusion models enables researchers of recognising the complexity of the context at hand and incorporating the mediating forces of the geographic and market context on diffusion of the innovation (Poirier *et al.*, 2015). Against this backdrop, review of literature reveals an absence of studies on BIM in SMEs within the Australian construction industry. In response to such a gap in the body of knowledge, this study is intended to provide a picture of the status quo of BIM implementation among SMEs in Australia drawing upon the principles of innovation diffusion in construction companies. This contributes to the field as according to Taylor and Levitt (2007) presenting a picture of different aspects of the current state of an innovation is a precursor to identify the most effective measures to suppress the barriers and enhance the uptake of the innovation. Additionally, the study intends to unearth the main drivers for Australian SMEs regarding implementing BIM on their projects. This is deemed necessary inasmuch for promoting BIM in any context the main purposes, the drivers of organisations and the level of their awareness of the requirements and challenges of BIM should be investigated (Gu and London, 2010).

BACKGROUND

Implementing BIM in construction projects would foster effective exchange of information among project members through establishing efficient logistics and procurement systems as pointed out by Demian and Walters (2014). In spite of such proven advantages, studies such as Newton and Chileshe (2012) demonstrate a grim picture when it comes to the implementation of BIM within the Australian construction industry particularly in SMEs. That is, according to Newton and Chileshe (2012) “...none of the firms with an annual turnover of less than \$10 Million were currently using BIM...”. The mantra of increasing the uptake of BIM within Australia has been an item of the agenda for both the federal and state governments, as well as professional associations as pronounced by AIRAH (2013). Nevertheless, it seems such attempts are merely focused on large-sized projects due to the common belief that larger firms possess the level of expertise and resources to adopt BIM as pointed out by McGraw-Hill (2014). Yet, projects delivered by SMEs might take advantage of BIM even more than large-sized projects as maintained by Arayici *et al.* (2011). That is, due to their shorter duration, small projects present more opportunities to introduce the use of BIM and the smaller size of organisations is advantageous in driving higher levels of implementation as enunciated by Engineers Australia (2014). Additionally, 3D visuals enhance the quality of multi-party communications and improve the outcomes of projects as asserted by McGraw-Hill (2014), which equally apply to small-sized projects delivered by SMEs. SMEs in the construction industry are relatively lower in terms of innovativeness and face particular barriers to harness the benefits of innovations including lack of resources and knowledge alongside unavailability of skilled personnel (Sexton and Barrett, 2003). On the other hand, increasing implementation of BIM in an organisation is contingent upon the positive perception of potential adopters of the ability of BIM in fulfilling their organisations’

particular requirements and attending to their drivers (Gu and London, 2010). In essence, an evaluation of benefits against challenges and required resources is the basis for making decision whether to adopt an innovation such as BIM or otherwise as described by Hosseini *et al.* (2015).

In this respect, the study by Aranda-Mena *et al.* (2009) in Australia and Hong Kong revealed that perceptions and drivers for implementing BIM were not identical for small and large-size companies. The study pointed out the discrepancy between the drivers, yet the nature of drivers for SMEs remained unnoticed. In the study by Olatunji (2011) it was revealed that different organisational models of SMEs require different training and hardware requirements to implement BIM and the cost of BIM implementation for SMEs was estimated to be higher compared against large companies. The former study paid scant attention to revealing the driving forces behind SMEs for adopting BIM and the effective practices specific for SMEs for embracing the benefits of BIM. The findings of the study by McGraw-Hill (2014) on BIM in Australia and New Zealand showed that contractors are lagging behind designers and architects in embracing the benefits of BIM while the most important drivers for BIM were almost entirely associated with abilities of BIM in reducing the number of errors and clashes and preventing reworks on projects. It also came to light that the level of BIM engagement for SMEs in Australia is noticeably lower compared against larger companies (McGraw-Hill, 2014) without providing reasons to justify such observations. In the same vein, Swapan and Craig (2014) argued that benefits of BIM for Australian companies are challenged by a number of barriers such as hardware and software requirements and the necessity of training alongside lack of necessary personnel particularly for SMEs and companies with fewer than 20 employees. As such the study was concerned with the barriers rather than the drivers for SMEs.

Within the south Australian construction industry, Newton and Chileshe (2012) argued that the main drivers for using BIM on construction projects include improving constructability, improving visualisation, detecting clashes and enhancing productivity on projects. The influence of the size of companies and lack of awareness as barriers to implementation of BIM on South Australian construction projects were also emphasised by Newton and Chileshe (2012). However, the study remained silent regarding the specific drivers for adopting BIM and the status quo of BIM in SMEs. In essence, review of literature as discussed above shows that previous studies on BIM in Australia have mostly used case studies of high-profile projects with a bias towards discovering the barriers to implementation of BIM in large-sized projects. Consequently, scant attention has been paid to the impacts of the firm size and uncovering the drivers explicitly relevant to SMEs. Thus, there is a conspicuous absence of studies on BIM in SMEs within the Australian context. Addressing such a gap in the body of knowledge has been the driving force behind conducting the present study as described next.

RESEARCH METHODS

The study drew upon a *mixed-methods sequential explanatory design* as termed by Ivankova *et al.* (2006) entailing two distinct phases i.e. a quantitative phase followed by a qualitative phase. This method has become popular for conducting analysis in a wide range of research fields. This is due to its ability to provide a broad understanding of the research problem (in quantitative phase) followed by refining and expanding the quantitative findings in more depth in the qualitative phase as

asserted by Ivankova *et al.* (2006). The sequence of *quantitative* → *qualitative* was considered because it was best applicable to context-based and contextual explanation of quantitative findings (Ivankova *et al.*, 2006). That is, such capabilities were in line with the objectives of the present study to conduct an inquiry in a particular context. The priority was with the quantitative phase and the results of qualitative were integrated into the findings of the quantitative phase as the preferred method suggested by Ivankova *et al.* (2006) for reporting the findings.

Quantitative phase

The sample of companies for the quantitative part was considered as a combination of the authors' own private contacts in the industry alongside Yellow Pages listing of the South Australia's telephone directory. This was regarded as a tenable approach for sampling as the same method was used for sampling SMEs by Mills *et al.* (2012) in Australia. A total of 326 invitations to complete the online survey were sent to SMEs in South Australia, which resulted in receiving 41 duly-completed responses, thus giving a response rate of 13%. Due to the lack of knowledge of the nature of the data and the relatively small sample size of the study, nonparametric tests were deemed more suitable as recommended by the seminal study by Siegel (1956).

Qualitative phase

Subsequent to the survey, a qualitative study was considered in order to provide researchers with better opportunities to answer research questions, assist researchers to assess the "goodness" of their findings. As explained in the previous section, the qualitative phase refines and explains the quantitative results through exploring participants' insights in more depth (Ivankova *et al.*, 2006). Furthermore, the sample size for the survey was considered relatively small, thus as stated by Venkatesh *et al.* (2013) the subsequent qualitative analysis served in the capacity of compensating the small sample size of the survey questionnaire. Interviewees A, B, C and D were working in SMEs with at least 6 years of experience. Interviewee E was the BIM manager of a large-sized company in which a wide range of SMEs as subcontractors were using BIM. Interviewee F was involved in training and education of BIM while interviewee G was the manager of the government body directly working with South Australian companies in promoting BIM. It was contended that such diversity in views and experiences would provide a comprehensive insight into the major aspects of implementing BIM in SMEs in South Australia.

RESULTS AND DISCUSSIONS

Profile of respondents

As illustrated in Table 1, the numbers of employees in the respondents companies were drawn from different sizes of firms whilst still falling within the category of SMEs (Number of employees < 200). As defined by the Australian Bureau of Statistics, (ABS, 2013), the size of construction businesses based on the number of employees could be classified as 'small' or 'medium' with up to 199 employees and 'large' employing more than 200 employees. Therefore, according to Table 1 perceptions of different sizes of SMEs were incorporated within the present study. The majority of the respondents were SMEs with more than 21 years of experience. As a result, the findings were deemed reflective of the perception of SMEs with adequate knowledge and experience within the construction industry.

Table 1. Tenure of the companies and the number of employees

Number of employees	Number of years in the construction industry			Total
	6-10 years	11-20 years	Over 21 years	
24 or fewer employees	4	6	5	15
25-114 employees	1	2	10	13
115-200 employees	0	1	11	12
Total	5	9	26	40

Practices and awareness

Examination of Table 2 shows around 65.9% of the responses for the highly ranked practice fell into the 'agree' and 'strongly agree' category. On the contrary, around 75.6% of the respondents were in agreement and aware of the challenges of BIM implementation. The implication of this finding demonstrates that despite the higher levels of awareness (usage, benefits and challenges), the uptake on the practices (usage and interest) remained rather limited. Besides, awareness of challenges is well above the level of awareness of the benefits and know-how to implement BIM. This observation sheds light on one of the major barriers to higher usage of BIM among the SMEs in Australia being a one-sided and negative perception of BIM implementation. To the best of the authors' knowledge no previous study on BIM has referred to such negative perception of BIM among SMEs. This finding was further confirmed by the interviewees who acknowledged that the main barriers could all be purported to be stemmed from perceptions and inadequacy of knowledge about the benefits and challenges of BIM implementation.

Table 2. Awareness and practices of BIM in SMEs in South Australia (percentages)

Category	Item	Frequency of responses (%)*						MS*	R
		SD	D	N	A	SA	Total		
Practices	Currently use BIM on our projects	14.6	22.0	14.6	26.8	22.0	100	3.20	3
	Interested in and supportive of using BIM	0.0	7.3	26.8	36.6	29.3	100	3.88	1
	BIM can be used in projects of all sizes	0.0	12.2	39.0	29.3	19.5	100	3.56	2
Awareness	Aware of the benefits of BIM	0.0	17.1	22.0	26.8	34.1	100	3.78	3
	Aware of how to use BIM	0.0	14.6	19.5	29.3	36.6	100	3.88	2
	Aware of the challenges of BIM implementation	0.0	14.6	9.8	39.0	36.6	100	3.98	1

Notes:*Frequency of responses and mean score (MS) based on valid $N = 40$ (list wise); MS = mean score where SA = strongly agree; A = Agree; N = Neutral; D = Disagree; and SD = strongly disagree; R = Ranking of individual awareness and practices sub items

Dominance of such one-sided knowledge of BIM in Australian SMEs becomes fathomable in light of the nature of common knowledge management practices in SMEs. As asserted by Scozzi *et al.* (2005) SMEs might be interested in a particular innovation, yet they usually ignore reliable available knowledge in the literature about the innovation. In the same vein, the interviewees were in agreement that SMEs have a tendency to accept positive aspects merely through first-hand experiences with BIM or through their peers and have not been successful in acquiring a comprehensive awareness of all major aspects of BIM.

Examination of Table 2 also shows that the least ranked practice was "Currently use BIM on our projects" (mean score = 3.20), with less than half (45%) of the respondents (SMEs) indicating using BIM to some capacity on their projects. This

finding further corroborates the assumption suggesting that the level of implementation in SMEs (48%) is lower compared to general implementation rate (64%) in Australia as estimated by McGraw-Hill (2014). The percentage is much higher than the estimation by Newton and Chileshe (2012) in South Australia in 2012 which is justified due to the time factor. Nevertheless, it is indicative of the large number of companies, which have opted to adopt BIM in two recent years in Australia confirming a growing trend towards BIM utilisation on construction projects as observed by Newton and Chileshe (2012). This was acknowledged by all the interviewees that a large number of construction companies are joining the adopters of BIM although they have glaringly different reasons and drivers for adopting BIM. Companies were divided about the suitability of BIM for projects of all sizes with 48% in favour of the idea, 40% with no idea and 12% were against it. This reaffirmed the discussions above implying that SMEs in Australia are not adequately aware of the values of BIM for small projects. Such an insight was explicitly emphasised by interviewees E and G stating that literally SMEs have a limited knowledge of potential benefits of BIM on projects as observed in South Australia by Newton and Chileshe (2012). Another reason for such low level of awareness of the potentials of BIM was ascribed by the interviewees to the simplicity of the projects delivered by SMEs which could be executed with traditional methods without requiring any awareness of innovative methods. In addition, interviewees were of the view that envisaged values of BIM for SMEs only occur through using BIM continuously because investing in BIM for a one-off project is not justified for SMEs. As a result, accelerating the use of BIM in Australian SMEs depends on higher levels of implementation on large projects, incentives by the government to justify the costs, providing knowledge and training by professional bodies and the most important of all, pressure from the clients as asserted by the interviewees. As postulated by the interviewees attempts for promoting BIM in South Australian SMEs should concentrate on clients as the main decision maker and “...the guy who draws the check...”. Nonetheless, 67% of companies expressed their interest in BIM and indicated that they are supportive of BIM implementation on their companies in future. Such avid interest in BIM among Australian companies was reported previously by AIRAH (2013). As observed by Newton and Chileshe (2012) that large number of SMEs will progressively join the adopters of BIM in Australia due to their increased awareness of the technology and the necessity of maintaining their competitiveness in the market. In view of such a strong role ascribed to the awareness of BIM advantages in affecting BIM practices, a Chi-Square test of independence was conducted among the indicators of awareness and the indicators of practices as illustrated in Table 3.

Table 3. Test of dependency of practices of BIM on awareness in SMEs

Practices	Awareness		
	Awareness of the benefits of BIM	Awareness of how to use BIM	Aware of the challenges of BIM implementation
Currently use BIM on our projects	34.41 (0.001, 12)*	38.66 (0.00, 12)*	37.32 (0.00, 12)*
Interested in and supportive of using BIM	39.35 (0.00, 9)*	18.33 (0.031, 9)*	18.54 (0.03, 9)*
BIM can be used in projects of all sizes	28.26 (0.001, 9)*	10.06 (0.345, 9)*	8.74 (0.461, 9)*

Note: values in cells show (Pearson Chi-Square value (Significance level, *df*)); Highlighted values shows significant dependency

As inferred from Table 3, only “awareness of the benefits of BIM” shows a significant dependency with all the practices associated with BIM ($p < 0.05$). This resonated

with the statements of the interviewees frequently referring to the necessity of educating clients and companies regarding the values of BIM on projects.

Main drivers for SMEs

Nine items extracted from the literature were ranked based the mean score with the Coefficient of Variation (CV) used for rank differentiation where items had the same mean score. Table 4 summarises the results of analysis of drivers for implementation of BIM based on the overall sample of respondents.

Table 4. Drivers for implementation of BIM by South Australia SMEs

No.	Drivers	N	Mean*	Std. Deviation	CV	Rank
1	Facilitating cost-savings during design	41	3.73	.742	0.199	3
2	Increasing the ability to response to requests for information	41	3.66	.762	0.208	4
3	Earlier problems identification (e.g. clash detection)	41	3.93	.818	0.208	1
4	Improving cost estimation and control abilities	41	3.41	.741	0.217	8
5	Increasing clients' satisfaction	41	3.66	.825	0.225	5
6	Enhancing quality of the finished product	41	3.56	.808	0.227	7
7	Enhancing collaboration on projects	41	3.76	.860	0.229	2
8	Increasing the quality of construction details	41	3.61	.862	0.239	6
9	Improving the ability to meet sustainability needs	41	3.10	.800	0.258	9
	Average score		3.73			

Notes: Mean score where 5 = strongly agree; 4 = agree; 3 = neutral; 2 = disagree; and 1 = strongly disagree. The higher the mean, the more important the driver

The CV is reflective of the variability in responses of respondents; hence smaller CVs show higher levels of agreement on the item as indicated by the respondents (Sheskin, 2007). Examination of Table 4 shows that, the mean scores of the nine drivers for implementation of BIM ranged from 3.10 (improving the ability to meet sustainability needs) to 3.93 (earlier problems identification, such as clash detection) with an average score of 3.73. As inferred from Table 4, the nature of the most effective drivers (i.e. drivers ranked 1-4 are all linked with the cost-saving advantages and the values added through use of BIM to the business aspects of companies for Australian SMEs. The findings are consistent with an earlier Australian study by Newton and Chileshe (2012) which established that, among the construction companies in South Australia, the major drivers of BIM were all inspired by envisaged economic values of BIM for their businesses. The findings as reported in Table 4 are also in line with previous studies e.g. (McGraw-Hill, 2014). For example, McGraw-Hill (2014) study implied that reducing costs, reducing the number of clashes on site and clients' demands are literally the main motivators of non-users to adopt BIM. Similarly, interviewees were in agreement that non-user SMEs become adopters only if they see BIM as an adding-value method for their businesses. Meeting the requirements of clients was ranked as the fifth for SMEs. This insight reaffirms the arguments by Na Lim (2014) denoting that the most influential driving forces for pushing construction companies towards using innovations have roots in the demands of clients. As far as sustainability needs are concerned, SMEs regarded them as the least important driver of BIM implementation. This could be justified in view of the usual lack of awareness of SMEs regarding their environmental impacts (Revell and Blackburn, 2007). Thus,

for Australian SMEs the environmental values of BIM could not be influential to encourage non-users for implementing BIM.

The effect of size (evaluated based on number of employees)

To test the dependency of findings on the size of companies a Kruskal-Wallis *H* test as the nonparametric equivalent for the one-way ANOVA as recommended by Cronk (2014) was conducted. The results are reported in Table 5.

Table 5. Results of Kruskal-Wallis *H* test

Awareness and practices (see Table 2)		Drivers (see Table 4)	
Item	Significance level*	Item	Significance level*
A clear understanding of BIM	.419	Facilitating cost-savings during design	.618
A clear understanding of how to use BIM	.402	Increasing the ability to response to requests for information	.938
A clear understanding of challenges of BIM	.179	Earlier problems identification (e.g. clash detection)	.678
BIM fits all sizes of companies	.709	Improving cost estimation and control abilities	.937
BIM is currently used in our company	.678	Increasing clients' satisfaction	.058
We support using BIM in future	.476	Enhancing quality of the finished product	.736
		Enhancing collaboration on projects	.436
		Increasing the quality of construction details	.750

Notes: * Significance set at $p < 0.05$

As illustrated in Table 5, no significant difference ($p > 0.05$) was found among different sizes of South Australian SMEs in terms of their level of awareness, BIM practices and the drivers for BIM adoption on their projects. This finding was also consistent among the interviewees observations as none of them referred to size of the SMEs as a crucial item in defining the policy of company towards BIM implementation.

CONCLUSIONS

The findings of the study revealed that awareness levels of BIM amongst SMEs were much lower, and there is a biased negative perception regarding the requirements and the challenges of BIM implementation among SMEs. Therefore, in addition to providing some valuable insights on the current state of BIM amongst SMEs in Australia, this study goes beyond the available knowledge on SMEs by uncovering a bias amongst SMEs' awareness on BIM. Regarding the practices associated with BIM, the study revealed a significant association between awareness of the benefits of BIM and all aspects of practices mentioned in the survey. This was regarded as an evidence for the crucial role of raising the awareness of construction practitioners, clients and owners regarding the values of BIM for their projects. In the same vein, the findings on drivers highlighted the importance of business-oriented values of BIM for SMEs and the strong influence of clients' demands in leading SMEs towards BIM. These findings underscores the need for providing quantitative evidence of the cost savings and the benefits of BIM for businesses of companies in comparison to traditional methods as a fertile area for future research on BIM in SMEs. Finally, future studies should investigate available methods and approaches for customising an affordable BIM for simple and small-scale projects. The limitations associated with

having only South Australian SMEs as the basis of data warrant further research with in other states of Australia as well as other countries in order to broad-base the findings of this study.

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A CASE STUDY OF FOSTERING MULTIDISCIPLINARY IN BUILT ENVIRONMENT USING BIM

Chika Udejaja¹ and Zeeshan Aziz

School of the Built Environment, Northumbria University, Northumbria, UK

Building information modelling (BIM) has been made mandatory as part of the public procurement process in the UK. This move will by default encourage SMEs to develop their own capabilities to work with BIM technologies in order to maintain their market share or gain competitive advantage. It is argued that graduates with BIM expertise will be high in demand and will also have a profound effect on the sector and high project performance. This paper argues that the industry should look to the construction related education providers to instil students with awareness of BIM concepts and principles. This trend must be underpinned by educating and training BIM users and preparing future industry participants by modifying the curricula of architecture, engineering and construction and construction related programmes. The research will use case study approach to capture data from key staff, students and documentary evidence from two universities, one in the north-east and the other in the north-west. The paper will outline issues encountered and make recommendations on how best to improve the curriculum. The outcome will lead to the development of a strategy of how BIM activities can be incorporated in an effective learning methodology for both staff and students.

Keywords: building information modelling, best practice, assessment, teaching and learning.

INTRODUCTION

The construction industry is vital to the economies of most developed countries. Despite its importance, it has been established that productivity has declined over the past three decades and that the industry is extremely inefficient compared with other industries (Briscoe and Danity, 2005). The construction industry has also been described as extremely fragmented and lacking collaboration between supply chains (e.g. Latham, 1994; Egan, 1998, 2002). Researchers working in this area have shown that the quality of project delivery has declined over the past 20 years and that poor delivery is contributing to the increase in project costs (Liu *et al.*, 2011; Ilozor and Kelly, 2012; Singh and Holmström, 2015). In the light of the delivery issues, changes have been recommended that would involve integration of supply chains and also promote collaboration. Many proponents have identified BIM as a technology and process that can create value within supply chain and promote learning. BIM is a visual database of building information and it supports integrated design and construction process. It has been shown that the proper use of BIM can improve quality of construction, reduce project delivery time, and reduce construction claims and support sustainable construction (Eastman *et al.*, 2008; Volk *et al.*, 2014). Uptake of BIM technology is also encouraged by recent push towards sustainability, lean construction and drive towards concurrent ways of working. BIM technology and

¹ chika.udeaja@northumbria.ac.uk

processes are increasingly being seen as key enablers for realising a collaborative working environment, by enabling multiple disciplines to work together using a shared building model. In the UK, BIM is increasingly being seen not just as a technical process to determine the likely performance of projects but a valuable tool in the mediation between many associated stakeholders with their differing visions, numerous requirements and variation in their expertise, and as a valuable process to promote learning and managing information (Smith and Tardif, 2009; Succar, 2009; Gu and London, 2010; Jung and Joo, 2011; Ilozor and Kelly, 2012).

The emerging role presents new and considerable challenges for Architecture, Engineering and Construction (AEC) industry and more importantly the training providers. MacDonald and Mills (2011) identified that current AEC education in the UK rarely involved collaboration between students training for the AEC professions. There has been a demand from AEC academic providers to develop project-based modules to mimic real-life construction projects involving close collaboration between multiple disciplines. Attempts to integrate multiple construction disciplines using various curricular developments have been going on for almost a decade (e.g. Fruchter, 2003). However, the education sector is falling behind in this respect. The use of BIM is widely recognised as having the potential to change the way building projects are run by facilitating collaborative working practices that engage all design team members at an earlier stage in the design process, aided by BIM tools. Currently, graduates with collaborative design skills and BIM expertise are in high demand to develop innovative and collaborative working practices using BIM. Resultantly, there is a growing interest in using BIM as a core to enhance inter-disciplinary collaborative working within AEC education. Because of the growing influence of BIM, Mulva and Tisdell (2007) rightly define BIM as a “*new frontier for construction education*”.

To address these needs and to provide students with an opportunity to work on a realistic construction project, there is a gradual and consistent push toward adoption of BIM in the under-graduate/post-graduate curricula and a number of project based single/multi-disciplinary project based modules have been launched within two northern universities. Some of these modules involve students from multiple disciplines including Building Services (BS), Construction Management (CM), Architectural Design Technology (ADT) and Quantity Surveying (QS) working together, while other modules involve close collaboration between students from a single discipline. Also, across different modules, students are being encouraged to deliver their project work using BIM technology.

Authors' experience of teaching and assessing inter-disciplinary and multiple disciplinary modules shows that collaboration amongst students often takes place at a superficial level. In examining the current status of engineering education by Huntzinger *et al* (2007), a striking pattern emerges in the form showing that the curriculum lack relevance to actual practice. As graduates of engineering education system, authors' can attest to the vast disconnect between engineering curriculum and the actual practice. The importance of connecting the curriculum to the society is well documented in research work by DeHaan (2005); Wong *et al* (2011); Richards and Clevenger (2011); Gutierrez (2014). As a result, the assumed collaboration AEC education has a tendency to take place on a very superficial level, leaving students unaware of the connection between the curriculum and the actual practice. Students address simple elements out of context. It is difficult to see how individual elements relate to the whole building and interact with one another e.g. linking construction schedule to design model or linkages between quantity take-off and actual design. In

essence, true spirit of multi-disciplinary collaborative working is often not achieved. Also, the way students operate in multi-disciplinary modules does not mimic environment of collaboration and the actual working methodologies found in construction practice. The entire vision of the exercise to bring in different perspectives and different set of goals from multiple disciplines are not adequately achieved. Traditionally Architects have focused on building design, CM have focused on management of construction process, QS have focused on cost and take-offs. Curriculum was developed to reflect such domain focus. A key objective of multi-disciplinary modules is to enable students to see how their discipline-specific work fits in with the whole. However, with different disciplines not integrating well, this vision is often not achieved.

This paper investigates existing challenges in facilitating multi-disciplinary collaboration between built environment students and determines the integrative potential of BIM technology to enhance multi-disciplinary collaboration. The subsequent sections assess and evaluate relevant literature to enable an understanding of BIM development in construction field, the benefits that it could offer to the construction industry as well as identifying the barriers that prevent adoption. The final section will discuss the existing research in BIM diffusion in academia. A key focus is on determination of best pedagogic approaches that needs to be adopted and key issues that need to be addressed to enhance multi-disciplinary collaboration using a shared building model.

LITERATURE REVIEW

The construction process and its success are influenced by various factors and choosing the most effective investment to improve the construction process is a very important decision. Popov *et al* (2010) identified that the growing diversity of disciplines, professionals, tasks, events in respect of the management during design and construction stages of projects, plus the more competitive cost, time targets coupled with higher quality expectations and the need for enhancing technology are the driving force of information modelling in the construction industry.

Barlish and Sullivan (2012) explained that the application of BIM has become more accepted and common throughout the industry, but there are major issues with the concept because of difficulties in both its definition and application. They stated that because the term BIM is often used by vendors for their marketing strategies, the definition of BIM has become confusing. Liu *et al* (2011) identified that BIM has evolved from CAD research and suggested that in order to avoid the complexity; they defined BIM in different terms from Model and design data to construction management. This research defines BIM as a model and a methodology. From a model perspective, BIM is a digital model of a building in which data about the building is stored and structured in such a way that the data can be shared between the project team (BSI, 2010). From a methodology standpoint, BIM is an enabling technology with the potential for improving communication among project team, improving the quality of information available for decision making, improving the quality of services delivered, reducing cycle time, and reducing cost at every stage in the life cycle of a building (Smith and Tardif, 2009). Succar (2009) noted that regardless of the different definitions and approaches to BIM, all definitions focus on the fact that BIM is a catalyst for change poised to improve collaborative working among project team, improve its efficiency/effectiveness and lower the high cost of inadequate interoperability. These potential benefits are compelling enough for

construction organisation and academic providers to adopt BIM principles and concepts.

There have been several BIM education approaches and applications of BIM diffusion in education are currently in place in various academic institutions. The BIM education approaches cut across various disciplines and sectors including construction, engineering, manufacturing and employing variety of strategies and concepts and the vast majority of these approaches focus on student-centred BIM curriculum development, BIM integration approach into construction curriculum and collaborative design and construction (Wong *et al.*, 2011). There is a consensus in literature that BIM education in universities are timely and appropriate in order to respond to industry challenges. It is widely acknowledged that introducing and incorporating BIM education in universities can yield very productive results for both students and employers.

There are a few on-going multi-discipline courses in UK and in other countries (e.g. Taiebat and Ku, 2010; Wong *et al.*, 2011; Clevenger *et al.*, 2012; Mandhar and Mandhar, 2013; Gutierrez, 2014; Underwood and Ayoade, 2015). Wong *et al.* (2011) further stated that academic institutions in many countries have started teaching BIM and have set up curricula for the integration of BIM into the existing courses related to the AEC industry. Although literature review reveals that there is a proliferation of BIM education diffusion in both academia and industry, however; in the UK the academic adoption are still patchy and limited to a very few universities. For the UK to fully diffuse BIM in the curricula, fundamental changes are required to address the issues that are associated with multi-disciplinary programmes. This research will investigate the best ways for BIM diffusion can be implemented in the UK universities and the challenges that come with it. The intention of the research is to develop a programme that facilitates collaborative working amongst multi-disciplinary students in the AEC field.

RESEARCH METHODOLOGY

The research adopted a case study approach to examine BIM diffusion in the curricula in the two universities. As part of the case study, a series of six semi-structured interviews were conducted with tutors and users in the two northern universities, particularly those involved in multi-disciplinary module delivery. A purposive sampling strategy was employed, selecting tutors and users with experience in BIM and collaborative working practices. Because this research is part of a larger research which aims to investigate BIM in curriculum development, the interviews were supplemented by the collection of materials from the larger research. Interview questions were directed towards current BIM practices in the two universities. During the interviews, the greater involvement and participation of the interviewees were essential to explore key issues in adopting BIM for multi-disciplinary courses. Thus, interviews were loosely structured. According to Fellows and Liu (2003), the advantage of loosely structured interviews is that more complex issues can be probed, answers can be clarified and a more relaxed research atmosphere may result in more in-depth as well as sensitive information. The disadvantages are that the data are time consuming and difficult to collect and analyse and there are greater opportunities for interviewer bias to intervene. In this case, advantages far outweigh the disadvantages. During the interviews, discussion primarily revolved around key issues as it relates to the BIM diffusion in the curricula. During the interviews, the topics under discussion were elaborated upon using laddering techniques, to avoid getting standard answers.

Laddering is a tool for uncovering subjective causal chains in qualitative interviews (Grunert and Grunert, 1995). In laddering, a series of consecutive probes are used to prompt the respondents to develop causal chains. Critical reflections also played a key role in the research process. Whilst interviewees provided insights regarding the methodologies and strategies of BIM practices in the universities, it also provided the challenges and barriers that exist in the current practices. The interviews were undertaken in early 2012 and middle 2012, during the initial study of BIM diffusion within the two universities. Whilst this small sample size does not allow for generalisation, it will provide insight as to the current perception of those teaching in this field, and their understandings of BIM application in the curricula. The interviews were digitally recorded, transcribed verbatim and subsequently coded using content analysis, to highlight consistencies and inconsistencies, patterns and themes (Silverman, 2001; Langdrige, 2005). Consequently, the findings have been developed into a narrative to construct a contemporary picture of BIM practices in the two universities.

RESULTS AND ANALYSIS

It is important to build learning on sound pedagogical principles. Confucius (450BC) rightly identified the need for an appropriate pedagogical process, when he wrote: *“Tell me, and I will forget, show me, and I may remember, involve me and I will understand”*. In order to achieve goals of multi-disciplinary collaboration, it is important that students from different disciplines work with a shared building model, analysing building data in varied ways to satisfy needs of their specific discipline (Figure 1). Authors’ observation of assessments of outputs in multi-disciplinary project shows that collaboration usually takes place only at a superficial level. For instance, in true sense there is little integration between construction schedules (CM deliverable) or quantity estimates (QS deliverable) and the building model (ADT deliverable). In a recent assessment exercise undertaken for Disciplinary Project Students, the author observed that students came up with widely varying estimates ranging from £1 million to £6.5 million for construction of a new building block. Quizzing students showed lack of essential quantitative and analytical skills amongst students. The dearth of quantitative and mathematical skills amongst engineering under-graduate students have been highlighted in various research studies and often attributed to decrease of entry level into the profession (e.g. Newman-Ford *et al.*, 2007; Overton, 2003).

Aforementioned concerns were addressed via involvement of professional practising jury in design, development, delivery and assessments of modules coupled with selection of real-life local projects at University of Salford. In addition to fulfil various academic assessment requirements, student teams were required to make formative and summative presentations to jury members and project stakeholders. This resulted in positive feedback related to enhancing student experience and in bridging the gap between academia and practice. Feedback from module evaluation included student comments such as: *“A local project provides a realistic feel. We can actually go to the site and explore the project ourselves. Such level of detail is not possible using a scenario-based make believe project”*. Another student highlighted that working on a real-life project help them build their project portfolio and help improve CV. Such observations are also supported by reviewing the relevant literature. In view of many experts, such problem-centred and project-focused teaching is fundamental to the teaching for collaboration (Boomer *et al.* 1992; Jordan, 1995). Such real world problem based approaches help students to become active

learners and encourage deeper learning, as highlighted by comments of one the interviewed tutors, “*Hypothetical scenario based project exercises are good for classroom learning. However, to prepare students for professional practice, it is important to have more complex real-world projects*”.

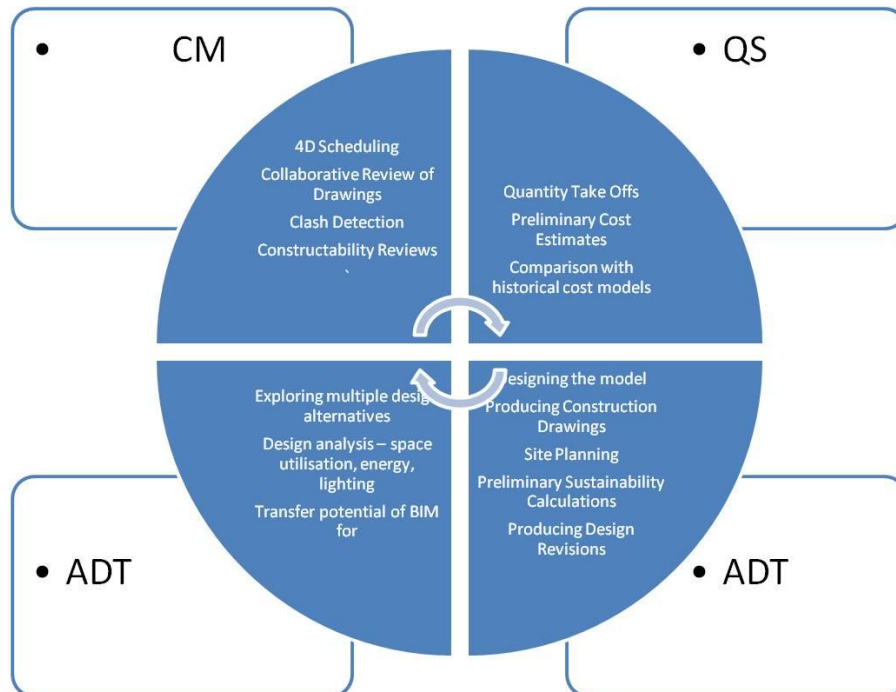


Figure 9: Integrating multiple disciplines using BIM

A key focus of this paper is to investigate various pedagogic approaches related to BIM-based model sharing. During the course of this action project, two separate teaching approaches were tried i.e. Bottom-Up (where students were provided to develop BIM models from scratch based on client’s brief) and Top-down (students were provided with an existing building model and asked to bring in interventions based on discipline specific needs). In bottom-up teaching strategy, students designed building super-structure, sub-structure, finishing and in the process, learned about key features of the BIM authoring tools and fundamental modelling concepts. Certain challenges were encountered while utilising bottom-up teaching strategy with multi-disciplinary teams where students worked in a linear or sequential manner.

Other disciplines (QS, BS, CM) rely on Architectural Design Technology (ADT) students to deliver the project design prior to executing their disciplinary tasks. Any delays by ADT students had a knock-on impact on multi-disciplinary students (QS, BS, CM), often resulting in team-conflicts and strain. There are certain challenges involved in teaching non-ADT students skills in model development. Firstly, use of BIM software is complex and understanding the ins and outs of a particular tool may take years of experience. Secondly, there are time constraints involved with limited number of class hours. The author used a lecture-lab combined delivery approach, where conceptual topics were covered in the first half, while computer-based work using hands-on instructions was carried on in the second half. During the lab session, the author observed varying level of technical competence amongst students. While some students were able to draw or manipulate the model using given set of instructions, others would struggle with basic tasks.

In contrast, in a Top-Down teaching strategy, there is no time-lag involved as a working building model is provided as part of the assessment brief. Thus, all disciplines simultaneously hit the ground running, focusing on their discipline specific interventions. Provided building model serves as a test-bed and provides students with an opportunity “*to flex their cognitive and social muscle in an environment where anything is possible and experimentation is safe, permissible, and desirable*” (Galarneau and Zibit 2007, p. 81). Top-down teaching approach works well with new students with little or no knowledge of the BIM technology. Also, provision of existing model helps to teach students fundamentals of modelling at a conceptual level. Once aware of the conceptual approaches and fundamentals of the tools, support is made available (e.g. online software tutorials) where students can self-teach to an advanced level. Another key advantage of providing students with a developed BIM is that visualisation plays a key role in generating student’s interests and makes them passionate about the subject area. This is also highlighted by an interviewee comments i.e. “*It is important for students to know their own discipline area. However, at the same time, awareness of what others is doing and how their work fits in the big picture, is important*”. Quite a few interviewees’ highlighted the fact that students put a lot of emphasis on applications and tools side, while not adequately addressing the conceptual or process related issues of multi-disciplinary collaborative working. This is highlighted by the following comment, “*It is important to address conceptual side of the multi-disciplinary process. Students often lack an understanding of key issues involved in multi-disciplinary collaboration*”. Use of appropriately software tools to enable students to correctly develop and visualise building objects, accurately extend the model, organisation of the model and development of information exchange standards to enable multi-disciplinary model based communication are important skills for students to have. Students lack of grasp of relevant software tools often lead to a compromise in accuracy and detailing of the building model. It is important to teach students key skills to enable professional use of the software.

CONCLUSIONS

Using a BIM-based shared building model approach helps to improve students’ understanding of the engineering design process, their ability to do discipline specific design using a shared model, helps improve communication skills using engineering drawings. It also helps them better integrate design model with cost and time.

The key benefits for using a BIM-based shared building model for multidisciplinary collaboration is discussed in detail throughout this paper. However, it is important to keep in perspective that using a shared building model approach, there is a potential to support a wider educational agenda. Firstly, the visual 3D models has the potential to generate deeper learning, by generating student interest and by helping them set their own learning agenda working together with other users and practitioners. Secondly, visual models help to improve student communication skills as they can more easily relate to a model. Better communication eventually leads to better teamwork, collaborative work and development of leadership skills. Lastly, using a BIM-based collaborative approach is a great way to bridge the gap between academia and industry. In exploring an analytical building model, students develop problem solving, quantitative and analytical skills make key judgments and decisions. Such skills help them in their development as a professional. BIM is an evolving technology and its adoption in curriculum taught at the two northern universities are still at preliminary stages. The authors intend to continue with the research process, to ensure that emerging BIM technology is best aligned to the needs of the industry and students.

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BUILDING INFORMATION MODELLING (BIM) SOFTWARE INTEROPERABILITY: A REVIEW OF THE CONSTRUCTION SECTOR

Shervin Yousefzadeh¹, John P. Spillane², Laura Lamont³, John McFadden⁴ and
James P. B. Lim⁵

^{1, 3 and 4}Shervin Yousefzadeh WDR and RT Taggart Architects and Engineers, Belfast, UK

²School of Planning, Architecture and Civil Engineering, Queen's University Belfast, Belfast, Northern
Ireland, UK

⁵Faculty of Engineering, University of Auckland, Auckland, New Zealand

Building Information Modelling (BIM) is continuing to evolve and develop as the construction industry progresses towards level 2 maturity. However, one of the core barriers in this progression is the aspect of interoperability between software packages. This research and paper stems from a Knowledge Transfer Partnership (KTP) where both industry and academia come together to address this shortcoming within the sector. One of the core objectives of this partnership and the aim of this study is investigating potential solutions to this barrier, while also developing best working practices to be applied in industry. Using one of the case studies from this partnership (a temporary steel structure), this paper demonstrates a potential solution to addressing interoperability within structural analysis and detailing packages, MasterSeries and Revit respectively. The findings of the research indicate that a process based approach rather than that of additional software coding as being the preferred solution. The results of this preliminary research will aid in the development of the topic of interoperability within the sector, while also developing the knowledge and competencies of the parties within the KTP. The findings are explored further, by providing an overview of the resolution process adopted in this case study, in overcoming the interoperability that arose as the project progressed. It is envisaged that this study will assist the construction sector and its adoption of BIM technologies, while also addressing the critical aspect of operability between software.

Keywords: building information modelling, BIM, interoperability, knowledge transfer partnership, structural analysis.

INTRODUCTION

Building Information Modelling (BIM) has varying connotations, not only within the construction sector, but throughout the built environment. As a result, there are numerous and often conflicting definitions of BIM; particularly within the construction sector. Notwithstanding this, one of the most recognised definitions provided is from the BIM Task Group (2013), which states that BIM is “*value creating collaboration through the entire life-cycle of an asset, underpinned by the creation, collation and exchange of shared 3-dimensional models and intelligent, structured data attached to them*”. Filippo Brunelleschi, the most notable master builder from the period immediately prior to the Renaissance, used BIM to vault the massive dome over Santa Maria del Fiore in Florence in 1419, as illustrated in Figure

¹ Shervin.Yousefzadeh@wdr-rt-taggart.com

1 (Garber, 2014). From this premise, it is noticeable that BIM is not just a 3D model, nor an innovative technology, but an overarching philosophy in the management and coordination of information among stakeholders. Therefore, this demonstrates that BIM integrates various forms of required data into one cohesive and integrated model, where all internal stakeholders to a project, including both design and construction, have the ability to digitally manage and integrate the often complex procedure of building prior to actual construction (Kensek and Noble 2014). A differentiating factor between traditional 2D drafting and 3D BIM modelling is that BIM objects contain intelligence within, often referred to as metadata, while in 2D Computer Aided Design (CAD) software, all elements are signified by a series of lines and points.

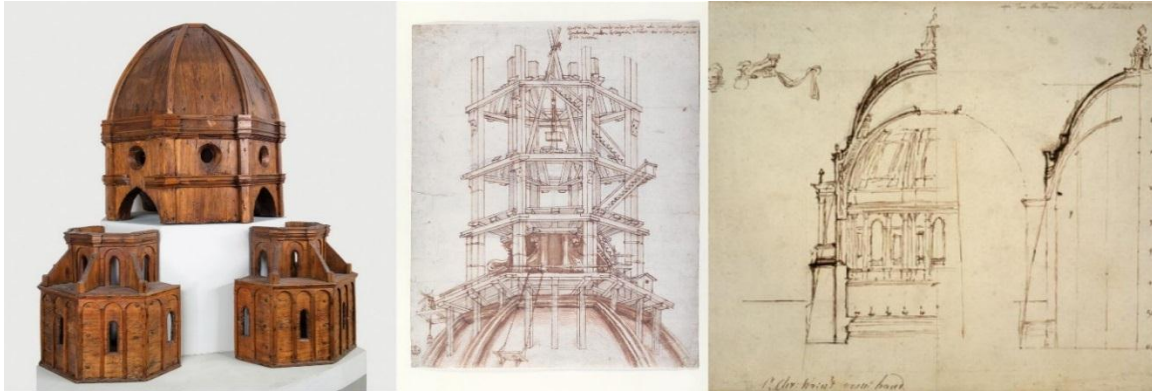


Figure 1: Filippo Brunelleschi 3D model and drawings for the Santa Maria del Fiore's dome

However, with this premise there emerges one of the core inhibiting factor in the widespread endorsement and application of BIM within the built environment - software interoperability. With the emphasis on the collaborative nature founded on data transfer, the ability of various software programmes and underlying data to interrelate and communicate effectively comes into question. The Business Dictionary (2015) defines interoperability as the ability of a computer system to run application programmes from different vendors, and to interact with other computers across local or wide area networks regardless of their physical architecture and operation systems.

Subsequently, software interoperability has emerged as one of the most inhibiting factors to the widespread adoption of BIM within the construction sector (Goedert and Meadati 2008). Various types of BIM interoperability exist including the lack of data transferring (missing data), erroneously translate data (objects imported differently in various software as illustrated in Figure 2), and files with a unique format that simply will not open in a different software platform.

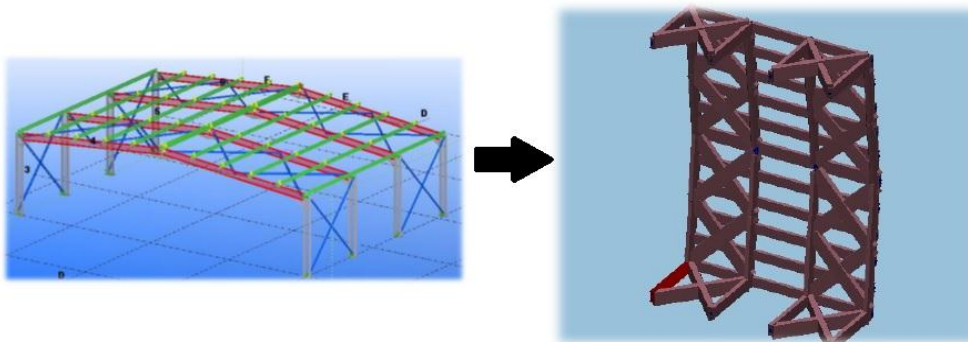


Figure 2: Wrong translation of data changed the default orientation of the structure

According to a GCR 04-867 report, published by the National Institute of Standards and Technology (NIST), the lack of operability between software platforms cost the United States of America approximately \$15.8 billion in 2002 alone, prior to the widespread emergence of BIM within the construction sector; a figure which equates to £10 billion in the United Kingdom. Therefore, it is essential that the construction sector, not only acknowledges, but takes proactive steps to mitigate and preferably eliminate interoperability between the respective software packages in the pursuit of attaining level 2 BIM as directed by the United Kingdom Government mandate. As one of the leading inhibiting factors curtailing the mass adoption and widespread implementation of the BIM process within the sector, this supports the aim of this paper and underlying research to address and provide solutions to industry. This research and subsequent findings will assist both industry and academia to mitigate this adverse characteristic, while also assisting software vendors and users alike, in resolving interoperability within the BIM process. Subsequently, through this and other accompanying research on the subject, it is anticipated that interoperability may be mitigated through hardware or software mechanisms that follow open standards such as Industry Foundation Classes (IFCs).

BIM AND SOFTWARE INTEROPERABILITY

Building Information Modelling, or BIM as it is more commonly referred to, is the integration and unification of communication among internal stakeholders to a project, with an intelligent 3D model as the platform on which to convey this intent. However, in the pursuit of facilitating this ideology, there is a necessity to accommodate the numerous of software platforms and the associated exchange of data. This has resulted in the emergence of an inherently complex and diverse aspect to the BIM process - software interoperability (Kensek and Noble 2014). Grilo and Jardim-Goncalves (2010a) highlight that the goal of seamless global interoperability is far from being realised, with Froese (2010) reiterating that with this change in management perspective, more operable information and communication technology must be adopted. Moum (2010) further illustrates and acknowledges that this trait is compounded due to its proliferation within stakeholder engagement, not only internally within an organisation, but more critically, also in external stakeholder engagement.

Regardless of the mechanisms used to convey such information, be it cloud or in-house server based systems, the subject of interoperability can inhibit such interactions. Redmond *et al* (2012) reiterate this premise, particularly in relation to inhibiting data exchanges using cloud based systems. Singh *et al.* (2011) provide insight into the aspect of BIM communication and facilitation using a server based system which concludes that a greater emphasis needs to be placed on the development and consideration of the technical aspects when considering hosting of a BIM model; thus minimising interoperability among stakeholders. Regardless Gu and London (2010) advocate that in order to facilitate BIM adoption within the Architectural, Engineering and Construction sectors, it is necessary to address the technical limitations inhibiting its widespread implementation.

Čuš Babič *et al.* (2010) acknowledge this including the aspect of interoperability within the sector, by highlighting that it is not a new phenomenon. To address this shortcoming, the introduction of industry foundation class or IFC files emerge, to assist in mitigating interoperability. However, Čuš Babič *et al.* (2010) concludes that interoperability is a significant factor which adversely affects numerous projects.

Tanyer and Aouad (2005) advocate the introduction and utilisation of IFC files to assist in the mitigation of interoperability while Isikdag and Underwood (2010) outline that it is still the preferred method to date. Grilo and Jardim-Goncalves (2010b) outline that the IFC file format allows the sharing of intelligent information contained within a BIM model; however, Steel *et al.* (2012) argue that further development and refinement is necessary to fully overcome the limitation of interoperability using this format. Redmond *et al.* (2012) aptly summarises the initial problem with IFCs in that they are not intended to store and carry all relevant data for all multi-featured construction processes; hence their limitations going forward.

RESEARCH METHODOLOGY

With the aim of this paper to develop potential interoperability solutions for industry and academia, there is a necessity to develop and articulate a clear methodology in doing so. This research is based on a detailed study of BIM interoperability between Autodesk Revit and Finite Elements Analysis software, Nemetschek Scia Engineer and MasterSeries, using two construction projects as case studies. A case study approach is adopted in this instance as Yin (2013) argues that it is the most beneficial approach in explaining present circumstances while also facilitating explaining a causal link. More than one case study is utilised as Yin (2013) advocates using multiple sources of information to facilitate triangulation to verify the results obtained. Yin (2012) advocates the use of an explanatory or evaluate case study research to explain and appraise the various interoperability aspects under scrutiny.

In order to facilitate the assessment of each of these software platforms, it is necessary to identify suitable case studies for inclusion in the research. A two stage selection process is adopted, where firstly six potential case studies are identified for inclusion in the research. To facilitate this selection process, criterion sampling is adopted where each of the selected case studies have to meet a set of requirements. The criteria included size (sufficiently large enough structure), complexity (sufficiently complex), and positive client consent for participation in the research. The various case studies are located throughout the United Kingdom. Once six potential case studies are identified, random sampling is then introduced to remove researcher bias in the identification of the preferred case studies.

Subsequently, two case studies are randomly selected. The first case study is a concrete structure (water treatment plant), where Scia Engineer is used and the second case study is a steel structure (retail unit), where MasterSeries is used for analysing the steel frame. In each of the respective case studies, two file exporting techniques are explored, due to their prevalence in the industry; exporting the model using Industry Foundation Classes (IFC), and exporting through a direct link between Autodesk Revit and the respective software under scrutiny (Scia Engineer or MasterSeries).

Industry Foundation Classes (IFC)

In 1994, Autodesk developed an industry consortium, known as the Industry Alliance for Interoperability, which later, in 1997, was renamed to the International Alliance for Interoperability (IAI). This consortium has developed an open and neutral BIM format called Industry Foundation Classes or IFC. According to Applied Technology Council (ATC) report (2013) *“The Industry Foundation Class (IFC) file type represents a means for sharing construction and facility management data across various software packages used in the architecture, engineering and construction*

industry and facility management industry.” In 2005, IAI was renamed again to BuildingSMART and since then it continuously develops and maintains IFCs. IFCs, which are critical and definite components of BIM file sharing, are used by various BIM software vendors to setup and facilitate a computer-readable model. This contains all the data and information of the parts within the model and their relationships, to be transferred among stakeholders within a project. There are six different versions of IFC available (1.5.1, 2.0, 2×, 2×2, 2×3 and 2×4), with the IFC 2×3 format used in this instance.

Bi-directional link between Revit and Finite Elements Analysis (FEA) software

Direct links are extensions (add-ons) and data exchanges developed to facilitate specific actions between two software platforms. In this instance, direct links are introduced between Revit and FEA software to facilitate the data exchange process. These extensions are direct links between one software and another, and unlike IFC files, they are not cross compatible and do not work with any other software or systems outside of those intended. Since these links are developed specifically for the specific software platforms intended, they do not take into account any external considerations or scenarios. As a result, the data exchanged is normally of high quality and the final result is more accurate in comparison with other interoperability methods. However, it is limited by the environment in which the data can be transferred. In this instance, a direct link between Autodesk Revit and Scia Engineer version 3.0.254, developed by CADS, and a direct link between Autodesk Revit and MasterSeries 2014 are used, to assess interoperability in the respective software platforms.

CASE STUDY ANALYSIS - CASE STUDY 1

The first case study for consideration is that of a water treatment plant consisting of a concrete and steel structure. This new water treatment plant is a leading facility, designed to meet the advanced needs in water filtration and treatment and is located in the United Kingdom. The reinforced concrete water retaining tanks and the steel framed superstructure, including crane beams, are modelled in Autodesk Revit Structure (Figure 3); however, for the purposes of this paper, only the concrete structure is exported.

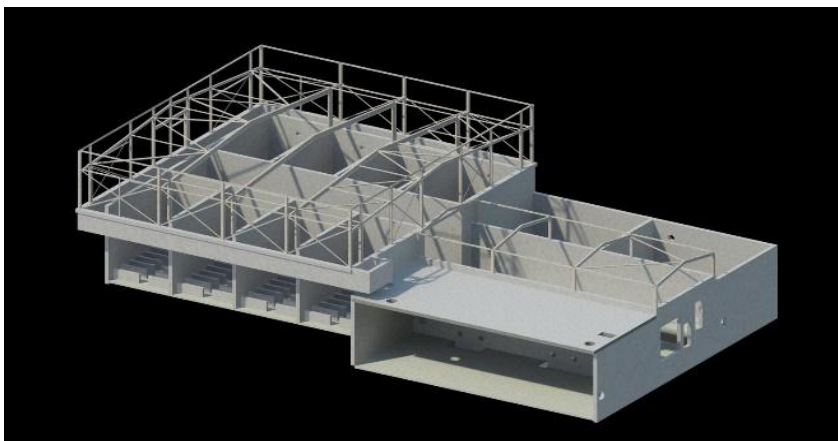


Figure 3: - Autodesk Revit model of case study 1: water treatment plant

Exporting to Scia Engineer

As outlined in the methodology, two formats are considered for migration of data from Autodesk Revit to Scia Engineer; firstly using IFC files and secondly, using a

direct link. In the first instance, when using IFC format, exporting and importing the IFC model is relatively straightforward, where the user is presented with a limited number of options to facilitate the process. In the second instance, in using the direct link approach, in order to use the add-on to export the model directly to Scia, the user must run Autodesk Revit using administrator rights. Unlike using the IFC method, the user has more options to consider during this process and can select desirable elements to be exported. Figure 4 shows the exported models in Scia Engineer.

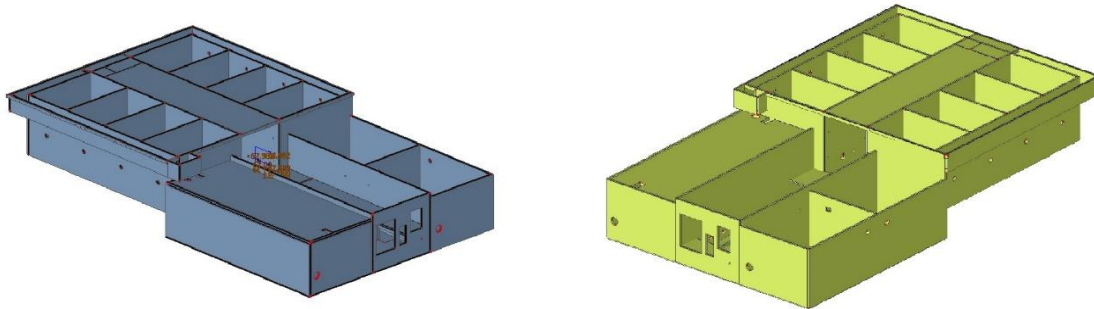


Figure 4: Exported models - IFC (left) and direct link (right)

Although the physical models look similar and appear to be accurate, further investigation reveals that the IFC model is imported with the incorrect materials assigned, while the direct link model has the correct materials allocated. In this case, where Scia Engineer fails to recognise a material using the direct link facility, it will provide the user with the opportunity to select the correct component manually. However, in the case of the IFC format, the user is not provided with such an opportunity within the IFC model and as a result, is one of the major shortcomings in this process based solution.

The Autodesk Revit and Scia Engineer direct link add-on not only highlights exported and non-exported elements within the Autodesk Revit model, but also provides a full report on the exporting process. As Figure 5 illustrates, the report represents a number of exported and non-exported elements and notifies the user of potential errors in the exported model, along with a suggested solution. Further refinement is suggested in this process where a model overlay is provided to assist in relating the notations with the respective areas of concern.

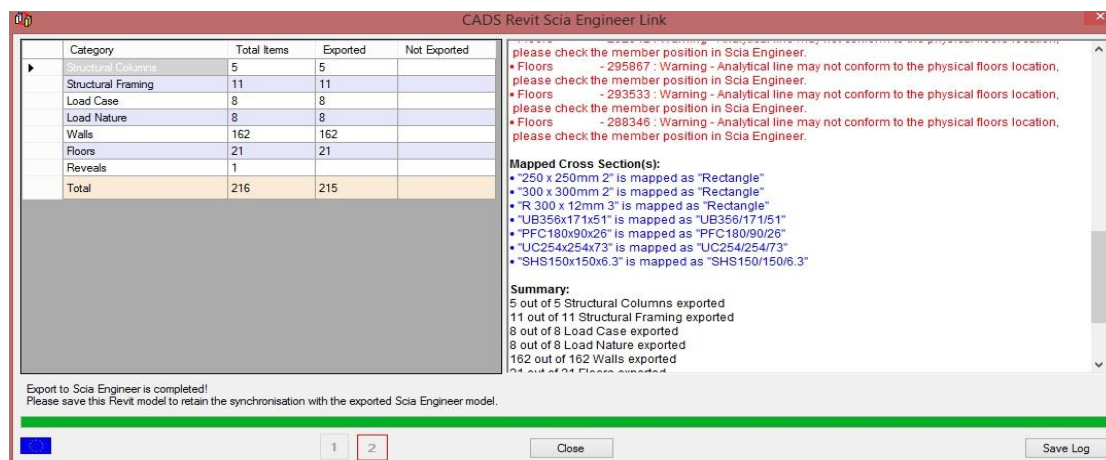


Figure 5: Sample report created by Autodesk Revit and Scia Engineer direct link add-on

One of the significant advantages of using a direct link format for file transfer, is the potential to facilitate a bi-directional transfer of data. This option will automatically

update the initial model in Autodesk Revit, based on any changes which have been made to the model in Scia Engineer. However, if any changes are being applied in the context of the IFC model in Scia Engineer, the user must re-save the file in IFC format and re-open it in Autodesk Revit. There is no option available to apply changes and update the initial Autodesk Revit model directly. However, there is a note of caution where bi-directional links are introduced. Such aspects as legal and liability assignment is called into question, where one stakeholder makes changes to a model which adversely affects another without consent. Additionally, the aspect of intellectual property is also called into question where interoperability is concerned. Such factors, although beyond the scope of this paper, must be acknowledged and counteractive measures assigned to mitigate or preferably eliminate such concerns between the various internal stakeholders to the project.

CASE STUDY ANALYSIS - CASE STUDY 2

In this instance, this case study is a three/quarter storey retail unit, bounded on three sides by a live shopping mall, retail units and car park access. The structural model designed using Autodesk Revit includes the steel frame, with composite metal deck flooring on a pile foundation and a reinforced concrete partial basement. This project is located in Northern Ireland and illustrated in Figure 6.

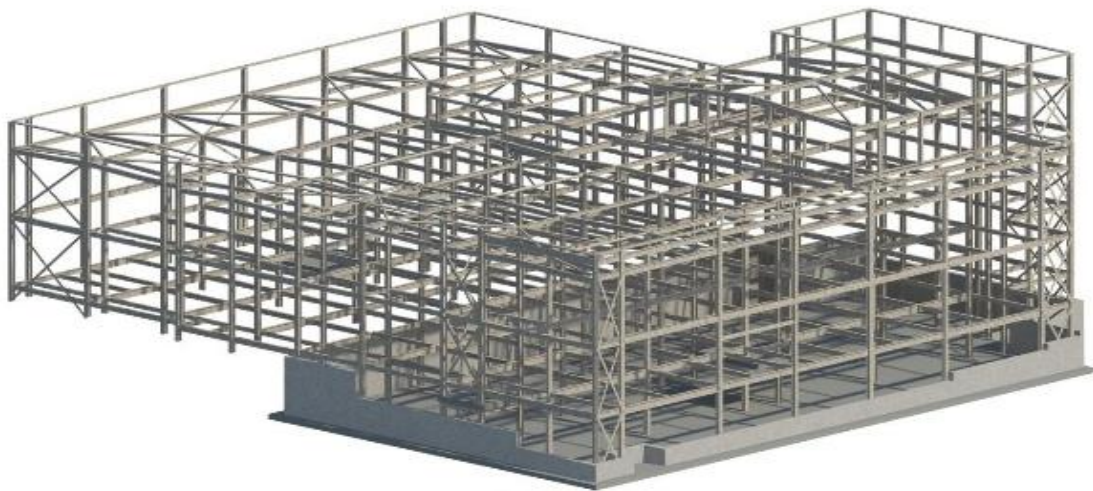


Figure 6: Autodesk Revit model of case study 2: retail unit

Exporting to MasterSeries

In relation to the second case study where MasterSeries is introduced to facilitate the structural steel construction, both IFC format and a direct link approach is adopted to assess interoperability. In the case of IFC, after saving the model in IFC format, the model is imported, extracted and loaded in MasterSeries. As mentioned before, exporting and importing IFC files is an uncomplicated process; however in this instance, MasterSeries offers a number of options before extracting the model, such as Y co-ordinate offset and importing or ignoring walls.

In the context of using the direct link approach, the user needs to open the Link Management Centre, where the add-on section is located. The Link Management Centre offers various options, for example, users can export the whole model or selected elements within the model. Moreover, the user can create a bi-directional link, which provides the ability to export the model back from MasterSeries to Autodesk Revit, or a unidirectional link, which is a one-way export to MasterSeries. Additionally, it is possible to map the steel sections and Revit Family manually in the

Link Management Centre. Both the exported models using the direct link and IFC format are shown in Figure 8.

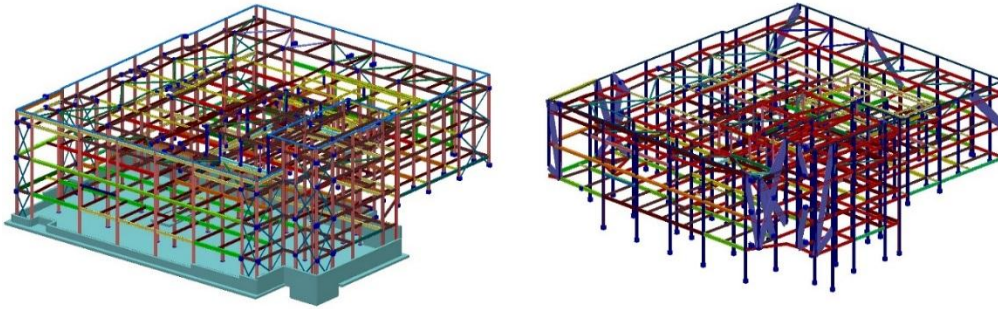


Figure 7: Exported models - direct link (left) IFC (right)

As Figure 7 demonstrates, concrete walls and slabs are omitted in the IFC model in MasterSeries. Moreover, the IFC model failed to recognise and translate one of the steel families in Autodesk Revit; thus numerous errors and omissions emerged. As a result and to compensate for this omission, MasterSeries replaces the omitted section with an incorrect and oversized section. In contrast, if Autodesk Revit and MasterSeries link failed to recognise an Autodesk Revit family, it prompts the user to define the component manually.

The Autodesk Revit and MasterSeries direct link has also a bi-directional functionality, which permits the export and import of the model between Autodesk Revit and MasterSeries. This feature facilitates updating the model in one software, based on changes which have been made to the model in another. Conversely, changes made to the IFC model need to be applied manually to the initial Autodesk Revit model. The Autodesk Revit and MasterSeries link can produce an export log (Figure 8), that contains information relating to the exporting process and shows the export summary; thus providing a detailed overview of the components exported.

```
4/14/2015 03:54:02 PM: Frames(Id=900233):P1 = P2
4/14/2015 03:54:02 PM: Beam/Brace not exported for element 900233 - The element has 1 nodes. Only 2 noded element are supported.
4/14/2015 03:54:02 PM: Frames(Id=901325):P1 = P2
4/14/2015 03:54:02 PM: Beam/Brace not exported for element 901325 - The element has 1 nodes. Only 2 noded element are supported.
4/14/2015 03:54:02 PM: Frames(Id=902603):P1 = P2
4/14/2015 03:54:02 PM: Beam/Brace not exported for element 902603 - The element has 1 nodes. Only 2 noded element are supported.
4/14/2015 03:54:02 PM: Frames(Id=904330):P1 = P2
4/14/2015 03:54:02 PM: Beam/Brace not exported for element 904330 - The element has 1 nodes. Only 2 noded element are supported.
4/14/2015 03:54:02 PM: Frames(Id=905116):P1 = P2
4/14/2015 03:54:02 PM: Beam/Brace not exported for element 905116 - The element has 1 nodes. Only 2 noded element are supported.

Export Summary:
Frames: 847 exported, 19 skipped
Columns: 114 exported, 0 skipped
Walls: 19 exported, 0 skipped
Materials: 3 exported, 0 skipped
Sections: 31 exported, 0 skipped
Thicknesses: 4 exported, 0 skipped
Floors: 5 exported, 0 skipped
Grid Lines: 19 exported, 0 skipped
Levels: 15 exported, 0 skipped
Boundary Conditions: 0 exported, 0 skipped
Rigid Links: 0 exported, 0 skipped
Frame Releases: 848 exported, 0 skipped
```

Figure 8: Autodesk Revit and MasterSeries direct link export log

One aspect of concern in direct link is the different format adopted in the numbering of the nodes. According to the MasterSeries, the algorithm used for numbering nodes in Autodesk Revit is slightly different to the one adopted in MasterSeries. However, it is possible to renumber all nodes, based on the MasterSeries numbering format, within MasterSeries, where an option is provided in the main menu of the software to do so.

CONCLUSIONS

Building Information Modelling (BIM) has quickly become the leading platform for the facilitation and dissemination of communication in the architecture, engineering

and construction industry; a factor evidence in the proliferation and emergence within the built environment. With this and the evolution of the BIM process and underlying software packages, interoperability emerges and has come to the fore as one of the leading inhibiting factors in the proliferation of the BIM process within the construction sector. The necessity of operability between BIM software, particularly between CAD and FEA software, is undisputed and is one of the clear failings which needs to be addressed.

This paper reviews two approaches to mitigate interoperability between these two software platforms; using IFC's and direct links within software packages. Direct links are developed to exchange data between two BIM software platforms, while IFC files can be opened and modified by various BIM software packages. This feature has brought both negative and positive viewpoints for IFC files as also iterated in the literature reviewed. First of all exporting IFC files is not complicated, and it does not need an extra add-on or extension to be installed; however, there is clear limitations on the data that can be transferred, thus limiting its success. Secondly, IFC files can be opened by almost all BIM software, including CAD and FEA software; however, this option has decreased the accuracy and precision of the exported model.

In contrast, direct links are extra add-ons which must be installed separately on each of the respective systems handling the models in question and they only work with two BIM software platforms on which they are designed. This is one of the core limitations of this process; however this has aided software developers to refocus more on the details and accuracy used within this file handling and transfer process. As a result, the exported model through direct links is usually more accurate than that of IFC model. Therefore, this paper highlights that, although Industry Foundation Classes (IFCs) are the means to exchange data and information related to a BIM project, using direct-link to transfer data is more reliable and accurate process.

However, there are additional points of concern emanating from this and other research on data exchange utilising the BIM process. Such aspects as the legal ramifications of integrating bi-directional links between working models, particularly between organisations and the subsequent liability that will inevitably ensue must also be considered and investigated further. Additionally, aspects such as intellectual property rights and ownership issues also emerge and must be considered by the industry before advocating the widespread success of mitigating interoperability outside of software and their supporting systems. Hence, it is suggested that further research be undertaken in these areas, to substantiate the findings herein.

This paper and others included in the literature reviewed, all argue that BIM interoperability is of concern, yet this aspect has yet to be resolved. This research demonstrates that this is still an issue, particularly in relation to BIM interoperability between computer aided design and structural analysis software; however, potential solutions are tabled and reviewed with varying success. Through a process based approach, industry and academia alike can mitigate and in some instances eliminate software interoperability through adopting a process based approach rather than relying on software coding, as is often the case. Subsequently, this can assist companies in the selection of the most efficient and appropriate method to facilitate the data exchange required between BIM software packages. It is envisaged that this paper; although only tabling initial findings from a knowledge transfer partnership, can assist in facilitating those who wish to adopt and implement a fluid data transfer

process encompassing the BIM process within their respective organisations and sectors as a whole.

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SEMIOTIC APPROACH TO BUILDING INFORMATION MODELLING BASED SERVICE MODEL

Bohan Tian¹ and Kecheng Liu

University of Reading, Reading, UK

Building Information Modelling (BIM) seeks to integrate information and business processes throughout the entire building life cycle. This technology is able to generate 3D models that semantically represent facility information dynamically over the life cycle of a building, but is limited when it comes to meeting the needs arising from the operation and management of facility services. There is little research which shows that the BIM model links to Facility Management (FM) systems. This paper presents a BIM based service model, which adds both a pragmatic and social aspect beyond semantic level to assist facility management services from a semiotic perspective. The pragmatics of BIM provide context for services of building operation. The social aspect is related to norms that govern service delivery. Service contextual information is to extend building classes represented by the UML class diagram. Norms are specified by a norm analysis method of a semiotic approach. The extended BIM will be able to provide service context information required by facility management systems to operate a building.

Keywords: BIM, facility services, semiotics, service orientation, norms.

INTRODUCTION

Buildings have been regarded as special and complex products that provide functional space enabling people to live, work and achieve. Built spaces not only provide users with infrastructure, but also a context within which services are required, e.g. HVAC (heating, ventilation and air conditioning) or specialist services. Administration of these services is within roles of facility management (FM). The maintenance and operation of buildings is often the longest and most expensive stage in the project lifecycle, and it accounts for approximately three times the construction cost. Furthermore, FM involves the management of all the facility services that support the core business of an organisation. An overview from the top level of enterprise services shows that facility services belong to the category of support services (Asgari *et al.*, 2009). Organisational studies show that organisational effectiveness can be improved by creating a total quality environment that underpins core business activities. Therefore, effective and efficient FM is vital to the building lifecycle management. Operating buildings by approaches of intelligent buildings (IB) (Clements-Croome, 2004) and intelligent pervasive space (Liu, 2010) makes a contribution to FM for optimising user comfort and energy consumption. New technologies and concepts developed in IB allow various service systems managed and controlled in an integrated manner based on sensor networks. Accordingly, the approach of IB has affected the way FM personnel operate and manage a building (Wong, 2005).

¹ tianbohan@gmail.com

Presently, FM is facing challenges in information management. FM is developed into an integrated service delivery process by adopting computer-aided and service-oriented paradigm across various FM services' systems. In such building environments, daily operations generate vast and heterogeneous information, and this management process is an intensive consuming resource. Services are operated and delivered according to personal preference and organisational policies in the form of rules, or norms relating to the allowed and desired behaviour of service systems (Noy *et al.*, 2007). Those features not only require integration of building information, technical engineering knowledge and understanding of the service process, but also align the semantic and knowledge-based building information model with service processes.

The use of Building Information Modelling (BIM) offers an effective approach to representing building semantics for design and construction by defining building objects and their relationships. Furthermore, the BIM system is a shared data repository and knowledge resource for facility information forming a reliable basis for decisions making during the lifecycle of a building (NBIMS, 2007). BIM can partially overcome identified semantic and syntactic issues in FM (Vanlande *et al.*, 2008). However, BIM does not support the consideration of building activities and the context of use, i.e. lacking pragmatic and social aspects from a semiotic perspective, which limits BIM as a through-life solution. Semiotics is a theory of signs, which provide an effective way to analyse complex sign systems. A building is a complex sign system, which allows stakeholders to utilise, interpret and interact with. FM services require different information to meet the needs arising from operations of services. This paper takes views from a semiotic perspective, specifically, from a semantic, pragmatic and social aspect, the upper three layers in an organisational semiotic framework to analyse information requirements for FM services. In this context, FM services take into account building space, buildings system and user requirements to achieve its objectives.

To improve and enhance the effectiveness of BIM for FM, this paper presents a semiotic approach to extend BIM. Accordingly, a thematic service model is developed. Such a specific domain model is not only able to provide essential service context information, but also links service norms to related virtual building objects in order to support the service delivery process in a collaborative and efficient way. The remainder of this paper is organised as follows. The next section introduces organisational semiotics (OS) used in the BIM extension, followed by a review of the state of the art in BIM for FM. The paper will then present domain requirements and norm analysis to capture norms in the service process, alongside with a case study of the BIM based service delivery to validate the approach. In the last section, a conclusion is drawn.

A SEMIOTIC PERSPECTIVE OF BUILT SPACE

A building is a complex sign system, which has its meanings. Different disciplines involved in the process of developing a building interpret this sign system from their viewpoints, which are reflected in the information models that they use. In operation and maintenance stage, built spaces such as offices provide affordances to support users' activities through FM services. Such enabling spaces can be treated with the notion of "*habitat*" (Anderson and Brynskov, 2007), which is delineated by the three physical dimensions plus the temporal aspect, with great emphasis on the utility and added value of the services to the user. FM service deliveries are organised

information-rich activities involving interactions between building systems, facility systems and users activities within organisations. The requirements for developing a through-life information model are not only technical, but also rather social and organisational. Therefore, acquiring knowledge and capturing information requirements, management and utilisation of such a socio-technical environment is essential to develop BIM for FM.

Semiotics (Peirce, 1931-1958), as a well-established discipline of signs and information, offers a comprehensive theory to understand the nature and characteristics of sign and information system (Stamper, 1996). A sign is something which stands out to somebody in some respect or capacity (Liu, 2000). A broader notion stated by Eco is that “*semiotics is concerned with everything that can be taken as a sign which is anything that stands for something else*” (i.e. words, images or objects) (Eco, 1976). Organisational semiotics (OS) is a branch of semiotics applied to understand organisations based on the use of artifacts and communication. OS regards organisation as an information system that is able to process and manage information, and study organisations using semiotic methods.

Organisational semiotic framework is an approach that systematically concerns with the use of signs. A built space or habitat can be interpreted at six semiotic levels, which are employed to derive information requirements for developing BIM for FM. Peirce conceived of three original divisions of semiotics, known as syntactics, semantics and pragmatics to study the properties of signs. In addition to the traditional three layers, Stamper (1973) added another three - physics, empirics and social effect. All these branches of semiotics are organised into an OS framework, which has been widely used in the design of information systems and organisational analysis (Stamper, 2000). More than that, this approach has been used in designing buildings (Glover *et al.*, 2004; Noy *et al.*, 2007). In the context of building domain modelling, the OS framework is used to capture different aspects of a building and how it reflects to develop IFC (Industry Foundation classes) based virtual models (Tian and Liu, 2014) and in analysing BIM system (Hartmann, 2012).

The bottom three levels relate to the physical infrastructure of a habitat. Physical level represents a section of physical spaces and time in a built space, i.e. geography, geometry and properties such as materials. Facility service management often takes into account the spatial and temporal aspect (e.g. a seminar room is scheduled with different events that require different services). The empirical level represents building architectural and mechanical designation that need to not only meet design specifications, but also comply with regulations and codes (e.g. the capacity of disabled toilet needs to meet certain standards in dimensions and facilities to assist the disabled for use conveniences). The syntactic level represents the requirements of topology of space and building systems, i.e. the layout of space and logical relationships between building system elements.

The top three levels are associated with the service feature of a habitat. The semantic level concerns meanings of built spaces, which provides the context that services are constructed. A space needs to be socially and physically defined for its functions and purposes, which are supportive for business activities. Such service context concerns building use constrained by limitations in a physical space. Pragmatics concerns the purposes of built spaces that realised by various services. What services that a built space can afford can be decided as long as the semantics of a space is built up. Facility services are functional based on the building systems and facility systems constructed

in built environment. The social aspect is related to social values created for building users through using services. To achieve service objectives realises on implementing norms to deliver services. In an organisation, norms (Stamper, 2000) govern people's behaviour. In respect to FM services, norms are the business rules that set during the service process to meet users' requirements. Norms can be rules or regulations that relate to service delivery.

BUILDING INFORMATION MODELLING FOR FACILITY MANAGEMENT

BIM is known as data rich, object-oriented, model-driven intelligent and parametric digital representation of facilities. There are various notions defined by different research groups. From FM's point of view, we adopt a notion of BIM as a central knowledge repository, which is able to manage the whole building and project information for the entire life cycle of the facility. Realising the significance of the post construction stage of buildings from perspectives of sustainability and cost efficiency, has gained increasing interests in the research of leveraging BIM for building operation and maintenance.

There are a few researches taking place in exploring BIM's role on supporting FM functions such as relocation, space management and building performance analysis, and so far it is still emerging (Eastman, 2011; Serginson, 2012). It is recognised that with providing life-cycle data inclusive of operational information, BIM has potential to support the FM service process (Azhar, 2011; Becerik-Gerber, 2011; Arayici, 2012). Building information for FM identified includes geometric, semantic and topological information (Schlueter, 2009). However, transferred data is limited to graphical and spatial information (e.g. room areas and attributes) and asset information, but not service context such as spatial and topological relationships (Akcamete, 2010). In addition, considering effective building operating and decision-making, it also requires a high-level integration of various types of information generated during the FM process.

The IFC (industry foundation classes) building data model is a neutral data format, aiming to describe and exchange information regarding building components in an objectified way, used in the AEC/FM industry (Buildingsmart, 2012). IFC's model supports domain information relating to building services, such as building controls domain. But the service systems defined in IFCs are not linked to facility services management. For instance, relations between service and systems, service requirements for spaces and service elements, which are concerned by FM operations at the operational level. In addition, considerable building services are yet to be included, which are required for the FM database from a management perspective. Furthermore, as the integration of building systems becomes a significant part of building design and FM, this niche area is worth being explored and addressed in the BIM model. Specifically, on the one hand, required service components property sets are insufficient; on the other hand, the knowledge of service engineering behind the data model is not represented, which is significant in understanding how the facility management workflow of building operations.

REPRESENTATION OF THE SERVICE MODEL

This research aims to develop BIM based service model, a domain model, which specifically supports facility operations with an IB concept. The service model is developed based on OS framework, alongside with IFC schema to represent domain

knowledge. FM service related objects, information and their relationships in the service model are represented in a visual format by UML (unified modelling language) class diagram. The class diagram enables the service model not only to follow the data structure and semantics of BIM, but also to represent related context information for service processes.

Daily operations of IB featured building management system (BMS) is based on rules and context information such as location and schedule, as well as building user's preference, which need to be pre-configured during construction commissioning phase. The context information is classified into three categories, user context, physical context and service context. The upper three levels of OS framework mainly concern information requirements for user and service context, while the lower three levels cover physical context. User context information covers building occupancy, users' profile, related policies and their preferences. Service context information refers to service requirements and service co-ordination. Given more context of building utilisation, integrated facility systems are able to better support facility service management towards intelligent building automation and energy efficiency.

UML class diagram represents the service model, which extended FM service concept to BIM (Figure 1). Addition to IFC model's classes such as space and wall, two classes that *scenario* and *service* are added on, while other related classes have been extended in both attributes and their relationships. At the semantic level, the service model further defines room functions by detailing scenarios of building utilisation. Scenario is a concept depicts a context of utilisation linking between zone, users' activities and required services. A room may have multiple functions that differ different scenarios accordingly. Scenarios could be defined separately depending on how an organisation is to use space and what services will be involved. For example, a scenario of lecture and a scenario of fire require different services in a same seminar room. At pragmatic and social level, service class is added in the service model to specify user's service preferences and requirements associated with spatial and temporal information. Service class stores service related information requirements, preference such as preferred temperature and humidity. Required services will be assigned to a particular scenario based on users' requirements.

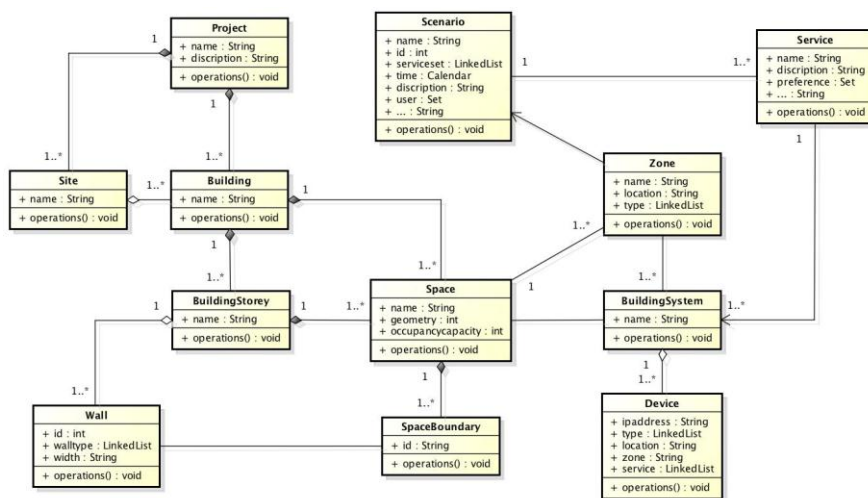


Figure 1: Class diagram of service model view

Added value of services can be achieved by the service model facilitating FM systems to deliver and co-ordinate services. For example, addition to building services, an

event booked in a space may also need catering service or parking service. Relevant service related information can be retrieved and exchanged through the service model. Furthermore, a service may need co-ordination of a number of service systems such as a fire service. Required building system could be assigned to a specific service. Main service related classes and their descriptions in the service model including zone, space and building system are shown in Table 1.

Table 1: Demonstration of main classes in service modelling

Classes	Information required	Class descriptions
<i>Service</i>	Service type, service properties	A concept describes facility services, such as HVAC, lighting, fire, security etc.
<i>Zone</i>	Zone type, user assignment, user schedule assignment	A spatial concept links to building management of systems and administration.
<i>Building system</i>	Building system type, system mechanical topology, operational properties	A concept describes building system topology, device location, operational attributes and functions.
<i>Space</i>	Spatial capacity, zone assignment	A spatial concept describes physical aspect and spatial containment of a space.
<i>Scenario</i>	Service assignment, service schedule assignment	A concept describes a situation which happens in a zone with specific service requirements reflecting actual use of building facilities

APPLYING THE SERVICE MODEL FOR SERVICE MANAGEMENT IN EDUCATION ENVIRONMENT

To elaborate the service model approach we adopted, we set up a building service model to assist facility service management in the Information Research Centre (IRC) at the University of Reading. Service co-ordination for booking and using a seminar room is simulated in this section.

Building Service Model Establishment

The context we applied is the IRC department purpose-built for education, which contains offices, a seminar room and relevant auxiliary spaces (Figure 2). The seminar room in IRC is a multi-functional room, which can take roles of small group lecturing, seminars and meetings with supporting facilities and furnishings in place. We have set up a semantic building model to represent IRC containing information required to reflect the context of building use, including spatial information, service preference, service requirements, scenario specification, etc. An example of scenario in the seminar room is presented in figure 3. The lecture scenario in the seminar room requires a number of services, such as room booking, HVAC, lighting, and other systems co-ordinated on the application level. The services such as lighting, HVAC and fire protection service are assigned and modelled into the lecture scenario. In addition, other facility services such as catering, cleaning and car parking service can link to the scenario if there is a need of related information for a corresponding service system. For example, car parks location, or catering requirements or furnishing requirements for the room can be specified.

The Process of Booking and Implementing Services

There are listed rooms that could be centrally booked for users through university's booking system. The room booking process has been identified and shown in figure 4.

For consideration of energy efficiency, BMS has been linking to central room booking system to deliver lighting and HVAC services according to room schedules. The activity diagram (Figure 4) shows a workflow of the facility management system of booking and utilisation of the room. Room booking system checks if the IRC seminar room is available at the requested time slot. If the seminar room is available, then the system will proceed to reserve the room with the specific event clarified, and then update a new schedule of the room. To achieve this task, relevant information is required to provide from service model, such as room capacity, identification of required facility services, group preference of the indoor environment (lighting, temperature), lay out and furnishing requirements. An event of lecture in the seminar room is generated in the BMS, as long as the room is booked. Required services such as lighting and HVAC will be automatically invoked and achieve indoor comfort according to user’s preference through system integration.

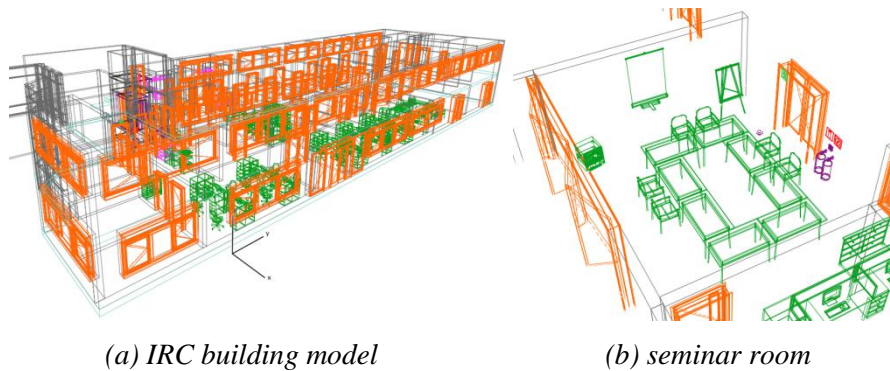


Figure 2: Semantic building models in a 3D view

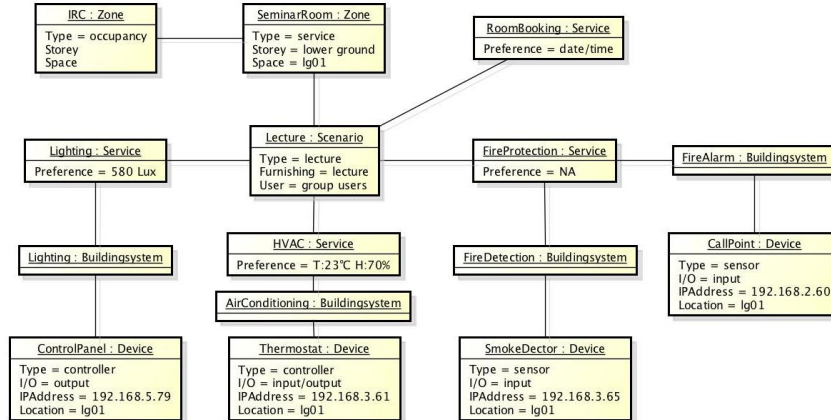


Figure 3: A scenario of lecture in the seminar room represented by UML object diagram

Fire protection service is compulsory under building’s regulations. No matter whether a building is occupied or not, the fire related systems have to be functional all times. IB features in fire protection services are achieved through system integration in BMS. Fire systems, such as fire alarm and sprinkler systems, would be integrated with other building systems, such as access control and HVAC. The bottom diagram of figure 4 describes a process of a fire occurring that requires a number of activities from building operations. In the case of an event of a lecture, multiple sub-services are invoked and interactions are triggered. For example, the access control system is interfaced with the fire system to release the controlled exit in the room. The camera in the room of a CCTV system is interconnected to monitor the situation by displaying

live videos. In addition, pre-selected cameras near the fire scene and on the evacuation route are able to be used to monitor the situation.

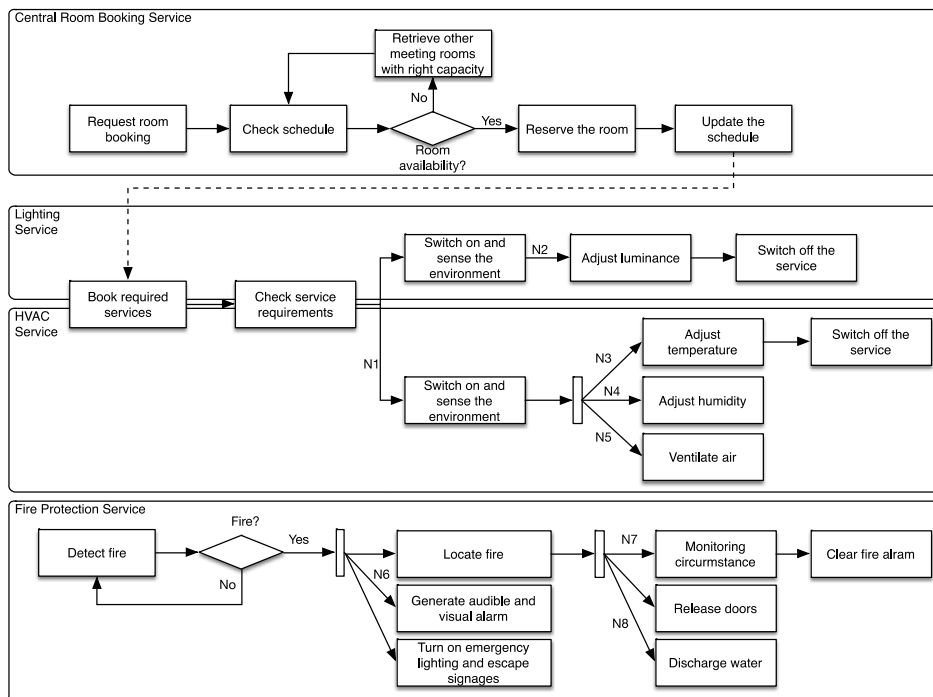


Figure 4: Facility services co-ordination process of booking and using a seminar room by activity diagram

Norm analysis method (NAM) (Liu, 2003) is used to elicit and represent knowledge about the organisations, and formalises the requirements. This approach allows capturing engineering and operational knowledge. Those are the important aspects we acknowledged in building utilisation that we defined as norms. In order to place BIM based facility services management, we need to associate operational data and building semantics with service process activities. As long as the context built up, the operational knowledge of facility service management is required to populate. There are operational rules to govern specific device systems in certain areas (a space or a zone) to deliver services. We adopt Liu's norm representation for knowledge as follows (Liu, 2000):

Whenever <condition> **if** <state> **then** <an agent> **is** <deontic operator> **to do** <action>.

Norms can be specified with using NAM as long as the workflow diagram is clarified, shown in table 2. The formal language version is for the BMS to execute. Lighting, HVAC and fire protection service implement according to specified norms. The agent represents each service system to perform certain actions. Virtual objects of devices (actuators or sensors) in systems relevant to the seminar room can be identified in the service model. Using the service model allows facility managers to define building utilisation and provide information for engineering and configuring service systems in BMS. By providing and linking context information related to utilization of the seminar room for lecture, FM can optimise service delivery according the schedule to save running cost. With integrating field-specific norms, the knowledge-based BIM system can enhance building operations in practice. A critical prerequisite to build such a knowledge-based system will be a full understanding of the service processes and activities and norms which are captured and represented in a BIM model.

Table 2: Norm specifications for the building operation activities in a process of service co-ordination

Norms	Service agent	Norm specifications
Norm N1	HVAC	<i>if</i> <time arrives 15 minutes before the seminar begins> <i>then</i> <agent> <i>is</i> <obliged> <i>to</i> <turn on the HVAC system in the room>
Norm N2	Lighting	<i>if</i> <Luminance level is lower than desired level> <i>then</i> <agent> <i>is</i> <obliged> <i>to</i> <switch on and dim up the lighting>
Norm N3	HVAC	<i>if</i> <temperature is lower or higher than desired temperature> <i>then</i> <agent> <i>is</i> <obliged> <i>to</i> <increase or decrease the temperature>
Norm N4	HVAC	<i>if</i> <humidity is lower or higher than desired humidity level> <i>then</i> <agent> <i>is</i> <obliged> <i>to</i> < increase or decrease the humidity >
Norm N5	HVAC	<i>if</i> <CO ₂ level is higher than desired level> <i>then</i> <agent> <i>is</i> <obliged> <i>to</i> <provide fresh air>
Norm N6	Fire alarm	<i>whenever</i> <a fire event is generated > <i>then</i> <agent> <i>is</i> <obliged> <i>to</i> <generate fire alarm>
Norm N7	Surveillance CCTV	<i>whenever</i> <the location of fire is identified> <i>then</i> <agent> <i>is</i> <obliged> <i>to</i> <display live video from the cameras in the fire zone>
Norm N8	Fire suppression	<i>whenever</i> <the location of fire is identified> <i>then</i> <agent> <i>is</i> <obliged> <i>to</i> <discharge water in the fire zone >

CONCLUSIONS

Facility services are managed in a trend of integrated and co-ordinated manners from a service-oriented perspective. Building information modelling has been proved to be an effective technology based methodology to provide required information for design and construction. BIM is also able to integrate building operation data resource as a comprehensive building data repository and platform. This paper presented BIM-based service modelling, which supports efficient facility service management by providing context information required during the service operation processes. Organisational semiotic framework is used to analyse information requirements, and extend BIM with stressing semantic, pragmatic and social aspects of built spaces, which add service context and link norms in the service model. Furthermore, norm analysis method is deployed not only to derive service rules for operation, but also to align BIM's virtual objects into the service operation process. The case of room booking and implementing co-ordinated services simulated showed that BIM based service model cannot only provide prerequisite context information required for different service requirements, but also facilitate service co-ordination in an energy efficient way.

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