LEVERAGING COLLABORATION THROUGH THE USE OF BUILDING INFORMATION MODELS

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Building information models are a major new means of design information communication and therefore they are of primary importance for successful design collaboration. However, in addition to communicating the design information, models are used in many different situations for different purposes by different stakeholders at different stages in construction projects. The developing model is a result of the different situations encountered in its production through the interaction of stakeholders. Consequently, it is important to evaluate different uses of models by different stakeholders collectively in order to understand the implications of these differences on models and therefore on design collaboration. The paper investigates this through two educational building projects and establishes the origins of these differences to identify how particular situations affect the developing model. Findings suggest that a successful collective use of models requires structure and planning but these plans need to be adapted to the situations in order to enable collaboration.

Keywords: BIM, collaboration, design management, modelling.

INTRODUCTION

Design in the construction industry requires different players with different backgrounds and foci to work together. Consequently, efficient interdisciplinary design collaboration is regarded as a critical success factor for construction projects (van Leeuwen 2003). In such practice, communication between different players of the developing project becomes critical, as each player needs to integrate their different sets of skills and knowledge (Sebastian 2011). The literature on collaboration in construction industry shows how a delicate balance between technological, organizational and people issues needs to be reached to collaborate successfully (e.g. Shelbourn *et al*. 2007). The primary condition to achieve successful collaboration is the establishment of the right social and organizational foundation (Homayouni et. al 2010). Technology, whether paper drawings or Building Information Models, needs to support this by facilitating transparent and reliable communications and this is an important determinant for collaboration in construction projects (e.g. Dossick & Neff 2011).

Among the technological solutions proposed to facilitate communication and therefore to support collaboration, Building Information Modelling (BIM) has become a significant topic for the UK construction industry. BIM can be defined as the process of development and use of a digital model of the facility intended to be built. The resulting product of BIM, the Building Information Model (model), has the ambition

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of being the central hub for all information about the facility from its inception onward. This information needs to take on many forms in its many roles through the life cycle of the facility. The conceptualization and use of the model as the central hub for all information require all stakeholders of the project to add to and use the building information depository through a collaborative effort (BIM Industry Working Group 2011; UK Cabinet Office 2012). Consequently, there is strong emphasis on inter-disciplinary design information sharing and collaboration in BIM related policies (e.g. BIM Industry Working Group 2011, BSI 2013) and in BIM related research (e.g. Arayici *et al*. 2011; Shafiq *et al*. 2013). Although it has been argued that the factors influencing successful inter-organizational collaboration and BIM practice are largely the same (Homayouni *et al*. 2010), how model based communication should operate in practice in order to enable the collaboration needs to be further explored.

In exploring this, the research assumes that the model is a major means of design information communication in BIM enabled projects and aims to establish how the communication of design, through collective use and sharing of models, needs to operate in order to leverage design collaboration. Through observations and interviews in two projects, the research enquires into how different disciplines decide their modelling approach, how they use other disciplines' models for their own purposes and what kind of modelling and other type of arrangements are taking place to maintain satisfactory design communication based on models. From this it establishes how models are not only used for sharing design information and design collaboration but also actively used for other fundamental functions such as information generation, storage, analysis, representation, control etc. during design development. The advantages and disadvantages (i.e. implications) of certain modelling approaches from design communication point of view are determined but more importantly the origins of these modelling approaches are revealed. It is concluded that different situations in which models are used have impacts on the modelling process and therefore on the resulting models and in order to be successful, planning and management are required to address these situations.

METHODOLOGY

This research takes a critical realist position (Ackroyd & Fleetwood 2000; Mingers 2008) as being the most suitable for the practical task of exploring the use of a same artefact (i.e. model) in different situations where different purposes are dominant. Critical realism sees the physical world and technology as real but recognises that human views and actions of those are socially constructed. The selected approach presumes that, ontologically, models exist independently (i.e. independent from its users) and they have the power of affecting the practice (i.e. the situations) in which they take place with their users. At the same time, it allows the research to capture how different uses of the models in different situations are differently constructed by users and in turn caused changes in the reality (i.e. materiality) of the model.

As part of a larger research project, data were collected from two design-build educational building construction projects. The client, the architect and M&E subcontractor were the same for both projects however M&E consultants were different. The enquiry used semi-structured interviews and observations of the projects to provide robust data so that a wide critical analysis of both ideas and practice could be undertaken. The first author regularly attended the design coordination and clash detection meetings of the second project but only audio recordings of clash detection meetings were used for first project. Insight was gained into in-discipline uses of the models through the semi-structured interviews. The observations in the design coordination and clash detection meetings were used to determine how models were used as design checking artefacts and what kind of modelling and other arrangements were required to satisfy the different uses of the model. The themes under which findings are listed emerged from the analysis of the observational data and previous interviews with projects' stakeholders. These themes were validated during the interviews and in cases when a particular reason for a modelling approach did not fit in an existing theme, a new theme was created. Through this the research gained an insight into how models were affected by different situations (i.e. different uses) that they were exposed to, in order to explore the implications of this on design collaboration.

COLLABORATION AND BIM

Collaborative design, in itself, is a disputed concept that is used interchangeably for different scopes of interaction in design process (Kvan 2000). Kvan (2000) citing Mattessich and Monsey (1992) described cooperation, coordination and collaboration as a spectrum where determinant of authority, risks for interacting parties, and sameness of missions differed. He argued that although there is strong emphasis in the literature on collaborative design, most of the times construction teams only cooperate and compromise. He stated that these are exactly what they should do because collaboration is time consuming and requires relation building. Consequently, he suggested loosely coupled information systems rather than closely coupled ones.

The point made by Kvan (2000) regarding the relation between the scope of social interaction and its relation to the type of information technology (i.e loosely coupled vs. closely coupled) is supported in a more recent study. Homayouni *et al*. (2010) argued that successful inter-organizational collaboration and successful inter-organizational implementation of BIM have shared *"theoretical categories"*. These are listed as: fostering integrated teams; implementing tools and strategies to encourage clear communication across the team; and developing transparent technology use. Importance of people issues in BIM enabled projects are also argued by others (e.g. Arayici *et al*. 2011; Olatunji 2011) and it has been stated that in inter-organizational settings, technology adoption process requires mutual adjustment to achieve successful inter-organizational collaboration (Taylor 2007). Similarly, BIM related policies also state that the conceptualization and use of the model as the central hub for all information require all stakeholders of the project to add to and use the model through a collaborative effort (e.g. BIM Industry Working Group 2011) and suggest closely coupled systems such as Common Data Environment (BSI 2013) for technically enabling this. Consequently, the BIM discourse often includes arguments for interdisciplinary communication and collaboration (Homayouni *et al*. 2010).

However, it has been reported that the level of collaboration in BIM enabled projects are lower than expected and/or not in line with the opportunities provided by current BIM software (e.g. Shafiq *et al*. 2013). Problems and concerns regarding collaboration in BIM practice have been studied both from technology-centred perspective focusing on functional requirements of the technology (e.g. Isikdag & Underwood 2010) and more comprehensive perspectives considering the developing relations between people, technology and processes for collaboration (e.g. Dossick & Neff 2011). The former category of studies focus on system design and aim to identify system requirements to technically enable closely coupled systems. The latter category aims to determine how organizational settings, in which dynamic relations between people and technology emerge, need to be managed to benefit from BIM.

Related to the concepts of loosely and tightly coupled systems are the ideas of Suchman (2007) on plans and situated action. Suchman discuss what makes artefacts *"interactive"* in order to explain the meaning people attach to computers in practice. Theoretically, this suggests that computers have intent *"as demonstrated precisely in this ability to behave in an accountably rational and intelligible way"* (Suchman 2007: 43). This intent is embedded in plans (both inscribed in the software and presented in the management of the task) and the actor's problem is to find a path from an initial state to a desired end state using the plans. In complex dynamic situations involving people the plans are inadequate and adaption is required in practice which becomes the point of situated action. This can cause problems for other members of a team if one member's adaption provides another's dynamic context as it deviates from the plan. The consequence as Gherardi (2012: 14) states is *"The concept of performance, in fact, makes it possible to regard work as an activity which follows a script, but whose interpretation is situated. It is an individual and collective activity that may consequently vary according to the participants involved in it, or those who are prepared to be involved"*.

MODELLING APPROACHES IN PRACTICE

As well as plans and situations the research analysis used a number of themes which emerged from the data itself. Central to this analysis is the expected (i.e. planned) *"BIM way of working"* which is structured (i.e. scripted) and technology driven. However, there are inadequacies in this that require *"pragmatic adjustments"* and the *"contractual requirements"* influence modelling approaches which respond to the situatedness of the activity. Further, the practicalities of developing a design through collective developing of a model require *"different levels of detail"* resulting from the collective and dynamic nature of design development. The ability to check design and coordination using clash detection is a significant part of BIM way of working but the practicalities of this need to be considered both technically and as a collaboration tool.

BIM way of working

In both of the projects, the same BIM platform was used by different disciplines which included an online document management tool to store and exchange design documents. The presence of different packages of the same platform allowed software interoperability. However, it was observed that there was a strong commitment to standardization of the way the model was created particularly through using naming conventions, work set contents and agreements on model contents. This allowed different parties to interrogate the model for their own design development purposes and also for managing clashes. These conventions were partly articulated in BIM Execution Plan (e.g. naming conventions). It was acknowledged by all the parties that creating and following a consistent structure for object development was the key to benefiting from the linked models and to produce the healthy development of design in BIM environment. However this alone was not sufficient due to the complexity of both modelling and design development such that regular on-going discussions were needed to keep the model consistent for all the parties.

The design teams stuck to in-built tools provided by the BIM software as much as possible to avoid the potential problems that might occur because of stepping outside the structured BIM way of working. Therefore, generic objects were only created when existing tools were not able to satisfy the design purposes at particular instances. For example, although they created an object family for furniture, the architects chose to model fitted furniture under a generic objects family. The reason for this was that they wanted the fitted furniture (e.g. reception desk) to be always visible even when they turned off the loose furniture. It took considerable discussion in both projects to decide what to include and what not to include under *"Generic Objects Family"* but a consensus was achieved and fewer conversations were required after this.

The BIM software has an embedded logic and understanding this logic was important in order to document the design correctly. For example, the editor didn't schedule the wall heights and did not show them correctly at some instances. When the wall intersected with a roof or ceiling, the editor automatically cropped it but when the object was considered in the designer view, it still showed the *"unconnected height"* which was the height before the automatic crop.

The BIM environment allows the creation of extensive connections between objects and the opportunity of assigning many attributes to the objects. However this requires approaching similar objects with consistency and planning in advance in order to know how these attributes would be used. For example, if rooms are defined as spaces, M&E discipline can use the model to conduct ventilation analyses. Similarly most of the objects can be scheduled automatically if defined consistently in the model. However counting on these automated functions brings its own risks because if there is a problem, it becomes really hard to find where it was generated from. Additionally, the designers need to understand the ways that measurements are performed by software to ensure that what was scheduled is actually what was designed. Curtain walls, for instance were problematic in this sense. The in-built curtain wall tool of the software, takes it is as an opening in the wall however curtain walls' fixing elements span beyond the visible opening in the model, thus, causing potential misunderstandings about the size of the curtain wall in schedules.

A useful feature for designers in BIM environment is that objects are created once and then developed over time. This makes it necessary to assign ownership to each object in order to ensure that they are adequately handled during the design development. This ownership of objects requires more coordination as objects are used by other members of the team. Similarly in BIM environments, different members use different views and the disciplines need to decide from which plane they should cut the model to obtain the view they want for it to be useful to them. Although there is the flexibility to create almost any views, the fact is that not everything is detailed in the model means that extra time is required to enrich the views with annotations.

Pragmatic adjustments to BIM way of working

The BIM way of working is determined by the functionalities of the software however the software does not work universally and so practical pragmatic adjustment need to be made. An example of stepping outside of the *"BIM way of working"* was about the in-built change tracking features of the software. Designers found the in-built change tracking features complicated to use. Therefore, to compensate, they decided to issue a cover letter every time they issued a new model where they detailed which parts of model were developed. Additionally, the auto-joint feature of the software did not satisfy the architects in some instances. For example in column-curtain wall joints, this feature extended the wall layers onto the column which was not what was wanted. After long discussions, the architects decided to black out these joints to force people on site to refer to 2D drawings where they could correctly document the joint.

In a similar way, the functionalities of the software were used for pragmatic reasons. For example, architects did not want to connect the walls to the slabs because slab objects were owned by structural engineer. They wanted to be able to turn off the structural elements and still have the walls visible. Although they acknowledged that this is against the logic of parametric design based on the fact that they fixed the heights of levels quite early in the design, they did not think the parametric feature was of value against other purposes. Furthermore, they created red 3D marker objects visible in all views to identify important coordination issues. As these markers were objects in the model, they also could schedule them to see all the pending coordination issues. Similarly, they created placeholder objects to specify objects that they don't own but they needed in order to coordinate their own designs. These placeholder objects were simple representation of the real object and were replaced by fully designed ones when the real owner of the object developed the design to the point that this object was needed. For example, radiators are created as placeholders (i.e. as empty boxes) by the architect to coordinate the room layout but later replaced by radiator objects by M&E designer.

Contractual issues

Contracts are important determinants for how the design is documented. The same views and drawings as pre-BIM practice are still created because the contractual documents in the background are based on 2D drawings. Therefore, as stated by all the interviewees *"it is still mainly based on 2D drawings but coordinated through 3D"*. There is a general disclaimer on the model which says that any information that exists in the model but not in 2D drawings should be checked with the owner of the object. As stated by an architect *"there are things that just don't work with a BIM way of working"*. Similarly, it was explained that the model as a design output can cause arguments between designers and clients. Although the scope and content of the model can be specified, it is impossible to specify every single detail about modelling and the client may end up arguing that the model is not developed appropriately. Therefore, 2D drawings were seen as being helpful to ensure that the design does its job properly and satisfies everyone.

Level of development of design and level of detail of the model

In the projects studied, the initial conceptual design used sketching software, and 2D drawings. The BIM model was created at RIBA Stage C. At Stages C and D mainly generic objects were used. At Stages E and F these generic objects are swapped out with custom ones (i.e. with the objects under custom families). This allowed the model to be flexible so that it could be changed quickly during design development. For example at Stage C, the design team only wanted to see that there was a door in a particular place but they were not interested in any particular property of that door apart from its location and approximate size.

Another issue about the level of detail of the model appeared in clash detection exercises. In many instances for the sake of efficient use of time, objects were deliberately left clashed with each other because of the fixed operation of the modelling software. For example the screed was left to clash with structural columns because everyone knew that the screed will only run up to the columns in reality. Another explanation given for this was that these clashes don't appear in most of the views, especially if they were set to medium or coarse level of details. However, although there were deliberate modelling decisions that do not reflect the reality, all the construction details were correctly included in the generated 2D detailed drawings and the annotations added on them.

The level of detail was also important when the coordination views were created. There was an ongoing discussion between the different disciplines sharing models with each other as each wanted to see different aspects and not see others. It was stated by all the interviewees that when a model was received from another discipline, it was very confusing to have it in the level of detail that the sender used. Therefore, agreements on what and how they want to see were made between the parties.

Design workflow

It was observed that the designers needed the design information stored in the models to develop their own design. Therefore the design workflow was connected with the model development. Individual disciplines use other disciplines' models as input to develop their own models and designs. When there was problem with the synchronization of the model development between the parties, 2D CAD drawings of other disciplines were used to coordinate in-discipline design to maintain the design development.

It was observed that it was impossible for individuals to make decisions only looking at the model because of the iterative and ever developing nature of the design. Therefore conversations were vital no matter how good the models were. These conversations were combined with 2D drawings which were complementary to the model. 2D drawings with their annotations and revision numbers told a necessary story and retained the message about the design intent. Similarly, because of the ever developing nature of design, the model was always incomplete in different ways for different disciplines. At any point in time, the model was only a snapshot of work in progress and designers didn't know what the final design would be. The iterative nature of design required jumping back and forward through different iterations. This caused problems in model based design communication. In one of the projects for example, an electric switch owned by M&E discipline was orphaned when architect deleted a wall which required communication outside of model environment.

Clash detection

In the clash detection exercises, only clashes between highest level object families were checked instead of setting more detailed rules. More detailed rules created an exponential increase in the number of clashes which were already felt to be excessive. Here again, the importance of object naming and structuring conventions was observed. These conventions allowed the designers to manually filter the clashes and to differentiate clashes created due to modelling issues rather than more important design clashes. For example, inset lights clashing with ceilings were never checked because the designers knew that these clashes were due to modelling issues; the lights were not embedded in the ceilings in the model because it was time consuming and such connections slowed down the model. Finally, clash detection exercises and any other model checks were always accompanied by a walk through the model. In many instances, designers detected design or modelling problems during these visual inspections rather than through clash detection exercises.

DISCUSSION

Use of the model as the central hub for all information requires all stakeholders of the project to add to and use the building information depository through a collaborative effort to ensure data integrity (BIM Industry Working Group 2011; UK Cabinet Office 2012). Consequently, there is need for an additional dimension of collaboration (i.e. in addition to design collaboration) in BIM enabled projects which arise from the collective use of the model. Although there is no explicit differentiation in literature between these two dimensions of collaboration (design collaboration and data collaboration), these are implied in BIM related policies (e.g. BIM Industry Working

Group 2011; BSI 2013) and in BIM related research (e.g. Shafiq *et al*. 2013). In order to understand better how design collaboration and data collaboration need to operate, the findings were analysed against the concepts of plans and situated actions. This will also be related to the establishment of closely or loose coupled systems. Clearly a work world dominated by plans is closely coupled and so experiences problems when its context changes such as in design development. It is generally promoted that the structured and accurate nature of the BIM model allows everything to be established through plans. This is challenged below.

What is described as *"BIM way of working"* in the previous section and the accompanying documents such as BIM Execution Plan and the agreements materialized in them (e.g. naming conventions) can be seen as plans. Collective development and use of models and their storage in a shared platform requires consistency. Project level BIM planning and structure informed by the plans inscribed in the technology by developers are required to establish this consistency. As a result, two types of plans can be articulated in BIM practice. First the plans inscribed in technology by developers and second the plans developed by the construction project team for consistency in order to enable collective development and use of models. The first type of plans allows technology to function properly. This can adapt to different construction projects only to the extent that the software offers a level of adaptation capability through the use of the embedded tools and functions. The second type of plans is created by the construction project team and gives legitimacy and accountability to model as a communicator of design information.

There are problems arising even with the first type of plan involving the data collaboration itself. Object-oriented design software (i.e. BIM software) and its associated rules and procedures have an embedded structure and scripts such as in-built tools, families, functions and data structure which fix and constrain the possibilities of design. However, the purpose of the software is to enable the development of a unique design artefact represented in the model, therefore, its users require the freedom to use different combinations of software features to accomplish the design. The modelling approaches in the case studies showed how the pre-developed rules and plans for the design and the model needed to be adapted to the different situations they encountered in order to accommodate the uncontrollable and unpredictable contingencies arising from these situations.

This adaptation takes place in and through the situated action. In any particular situations involving construction project design, it is argued that models are only a part of the purposeful situated actions. The models themselves are part of the situated action and so are in flux and influenced by the surrounding social and material elements; in addition they are interpreted in the unfolding situations. Therefore, the models are used and affected in different ways in different situations as was shown in the findings by the pragmatic adjustments to BIM way of working, the effects of contractual issues on modelling, the need for different levels of detail in different situations, the iterative and unfinished nature of ongoing design and the need to employ various inspection methods to detect clashes.

The collaborative construction project design work, itself, is run through social arrangements in which different meanings are attached to design by different designers and are negotiated and reconciled along the design development. Models, as a major means of design information communication, act as legitimate and accountable mediators of this negotiation and reconciliation process using the design information they represent. However, other means of communication such as phone calls, e-mails and meetings are needed between different stakeholders in order to sustain the social arrangements between the stakeholders and to reconfirm the accountability and legitimacy of the model as a trustable design information communicator. If communication through models replaces other means of communication justified by extensive planning, then models risk dictating or locking meanings rather than nesting them for negotiation and reconciliation. Therefore, models and accompanying plans should be positioned in design practice in a way that leaves enough space and facilitates meaning negotiation and reconciliation. This means that the way models are seen and the plans that are created should acknowledge and allow adaptations to different situations for successful collaboration.

Consequently, it can be argued that, on one hand model based inter-disciplinary design work requires close coupling and extensive planning to keep the software working and a consistent shared model for everyone. On the other hand inter-disciplinary design work is an iterative and evolving process that requires loosely coupled situations and flexibility to develop. Design is developed as result of various purposeful situated actions along the process and the design artefacts should afford unfolding and evolving nature of design work (Ewenstein & Whyte 2009). We argue that the tension between these two should be acknowledged and managed. This means that, in BIM enabled projects, management needs to accommodate loosely coupled situations in order to enable successful design collaboration.

CONCLUSION

In BIM enabled projects, the model, as a major mean of communication is an important factor that can improve collaboration. However in practice, modelling software is not ideal and the data is needed in different ways by different disciplines. Therefore, it is vital to achieve a harmony between uses of models as design development artefacts and uses of models as design communication artefacts. We argue that the models can only perform well as design communication tools if they also perform well as design development tools and the models which are successful in design communication are able to leverage collaboration in construction projects.

In this paper, it has been shown that there is a tension between plan driven, closely coupled model based design and the loosely coupled situations where design development is performed. Thus future work in BIM needs to explore how this tension should be managed. Although we observed some instances where users of the model *"hacked"* the software and improvised their own uses to make the model suit their needs, we argue that there are bigger potential opportunities that can be realized for better collaboration. We argue that once project particularities and requirements for design development and communication are established, BIM needs to be tailored according to the needs and particularities of the project and the software needs to enable this.

REFERENCES

Ackroyd, S and Fleetwood, S (2000) *"Realist perspectives on management and organisations"*. London: Routledge.

Arayici, Y, Coates, P, Koskela, L, Kagioglou, M, Usher, C, and O'Reilly, K (2011) Technology adoption in the BIM implementation for lean architectural practice. *"Automation in Construction"*, **20**(2), 189–95.

BIM Industry Working Group (2011) Strategy paper for the government construction client group. [online] Swindon, UK: The Technology Strategy Board. Available at: < http://www.bimtaskgroup.org/wp-content/uploads/2012/03/BIS-BIM-strategy-Report.pdf>. [Accessed 25 April 2014].

BSI (2013) PAS 1192-2 : 2013 *“Specification for information management for the capital / delivery phase of construction projects using building information modelling”*.

Dossick, C S and Neff, G (2011) Messy talk and clean technology: communication, problem solving and collaboration using Building Information Modelling. *"Engineering Project Organization Journal"*, **1**(2), 83-93.

Ewenstein, B and Whyte, J (2009) Knowledge practices in design: the role of visual representations as epistemic objects. *"Organization Studies"*, 30(1), 07-30.

Gherardi, S (2012) *"How to conduct a practice-based study: Problems and methods"*. Cheltenham: Edward Elgar Publishing.

Homayouni, H, Neff, G, and Dossick, C (2010) Theoretical categories of successful collaboration and BIM implementation within the AEC industry. In: Buwanpura, J, Mehamed, Y, and Lee, S. (Eds.), *"Proceedings of CRC 2010"*, 8-10 May 2010, Banff, Alberta, Canada. American Society of Civil Engineers, 778-88.

Isikdag, U and Underwood, J (2010) Two design patterns for facilitating Building Information Model-based synchronous collaboration. *"Automation in Construction"*, **19**(5),544-53.

Kvan, T (2000) Collaborative design: what is it?. *"Automation in Construction"*, **9**(4), 409-15.

Mattessich, P W and Monsey, B R (1992) *"Collaboration: what makes it work"*. Amherst H. Wilder Foundation, St.Paul, MN.

Mingers, J (2008) Management Knowledge and knowledge management: realism and forms of truth. *"Knowledge Management Research and Practice"*, **6**(1), 62-76.

Olatunji, O A (2011) Modelling organizations’ structural adjustment to BIM adoption: a pilot study on estimating organizations. *"Journal of Information Technology in Construction"*, **16**, 653-68.

Sebastian, R (2011) Changing roles of the clients, architects and contractors through BIM. *“Engineering, Construction and Architectural Management”*, **18**(2), 176-87.

Shafiq, M T, Matthews, J and Lockley, S R (2013) A study of BIM collaboration requirements and available features in existing model collaboration systems. *“Journal of Information Technology in Construction (ITcon)”*, **18**, 148 – 61.

Shelbourn, M, Bouchlaghem, N M, Anumba C and Carrillo, P (2007) Planning and implementation of effective collaboration in construction projects. *“Construction Innovation”*, **7**(4), 357-77.

Suchman, L A (2007) *"Human-machine reconfigurations: Plans and situated actions"*. Cambridge: Cambridge University Press.

Taylor, J (2007) Antecedents of successful three-dimensional computer-aided design implementation in design and construction networks, *"Journal of Construction Engineering and Management"*, **133**(12), 993-1002.

UK Cabinet Office (2012) *“Government Construction Strategy”*. London: Cabinet Office.

van Leeuwen, J P (2003) Computer support for collaborative work in the construction industry. In: Cha, J, Jardim-Gonçalves, R and Steiger-Garção, A (Eds.), *“Proceedings of International Conference on Concurrent Engineering”*, 26 – 30 July 2003, Madeira, Portugal. Balkema Publishers, 599-606.