Working Paper Proceedings

Engineering Project Organization Conference
The University of Edinburgh, Scotland, UK
June 24-26, 2015

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COLLABORATION IN BIM ENABLED DESIGN PROJECTS: EFFECTS OF INTEROPERABLE INFORMATION TECHNOLOGIES

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ABSTRACT

There is a growing awareness that the problematic nature of collaboration in construction design projects is further complicated by the use of interoperable information technologies (IT) in Building Information Modelling (BIM) enabled projects. Consequently, there is a need to better understand the ways interoperable IT get involved in inter-disciplinary relations and affect mutual engagement of different design members. Findings from the study of a BIM enabled design project are analysed using the concept of interdependencies in the interactions between practitioners and their organisations. The paper draws a distinction between "model interdependencies" and "design interdependencies" concerned with the IT and the design task respectively. This distinction helps to deal with the complex nature of practice by expressing the different needs people have in their task interactions using technology in organisations. It is concluded that the conflicts between model and design interdependencies cause segregation into separate model development and design development at the organisational level. Project organisations should be aware of this and take necessary social and technological precautions to achieve better design collaboration.

KEYWORDS: BIM, collaboration, design, interdependencies, interoperability

INTRODUCTION

Interoperability of information technologies (IT) refers to the ability to exchange information between different software packages (Ide & Pustejovsky 2010). In Building Information Modelling (BIM) enabled design projects, IT interoperability allows different design team members to contribute to and use data from a shared data repository (i.e. the information model / model) within which design data are stored in a unified and structured way. This is referred to as "integration", in the sense that design data from different design team members are connected together through pre-defined and / or user defined rules (i.e. parametric) (e.g. Whyte 2011; 2013). Such digital integration of design data has been promoted as an enabler of better design team collaboration in BIM; this includes enhanced (and sometimes automated) information generation, analysis, presentation and sharing capabilities (e.g. UK BIM Industry Working Group 2011).

IT interoperability requires specified data formats, communication protocols, and other formal structures to enable communication and data exchange between different packages (Ide & Pustejovsky 2010). In this new design production situation, collaboration is defined by, or at least framed by, data interchange. However, collaboration as mutual engagement is less clearly addressed by data interchange and the implications of mediating collaboration with IT are lost. Previous empirical research has shown that, in construction design projects, digital integration of design data has significant effects on the way design projects are organised (Whyte & Lobo 2010; Whyte 2011). It has been further shown that these effects can become counterproductive for design team collaboration depending on how

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interoperable IT are framed and used within the project organisation (Neff et al. 2010; Dossick & Neff 2011). Organisational situations where formal, rule based, linear logic of current interoperable IT operations obtruded upon the inter-disciplinary, iterative, to be physically applied, developing and dynamic character of construction design have been described in BIM enabled design projects (Dossick & Neff 2011; Whyte 2013; Cidik et al. 2014). Studies have shown that, in practice, these situations need to be negotiated to be settled and lead to improvised skilful combination of digital and non-digital practices for collaborative accomplishment of the work (Dossick & Neff 2011; Whyte 2011; Cidik et al. 2014). Consequently, new approaches to research into digitally integrated construction design work were urged for critically questioning the interoperable IT in order to achieve a more practically relevant conceptualisation of technology and interoperable IT mediated practices (Whyte 2013).

This paper explores how collaboration is practically accomplished in BIM enabled design projects and critically questions whether the interoperable IT really do support collaboration by facilitating purposeful mutual engagement between the design team members. In particular, it investigates the interdependencies between different members of the design team in the context of a BIM enabled construction design project. Interdependencies within an organisation imply coordination requirements between parties (Thompson 1967; Bailey et al. 2010) and are therefore important to be investigated in the context of collaboration in BIM enabled projects. The paper draws a distinction between "model interdependencies" that refer to the interdependencies imposed by rule based digital integration of design data and "design interdependencies" that refer to other interdependencies that were considered by design team members. Two events that were observed in the collaboration practices of a BIM enabled design project are discussed through the lens of model and design interdependencies.

Adopting a practice-based view of organising (Gherardi 2012), the discussion is further extended to the organisational level through the associations that are made between the findings from practice (i.e. the events) and the organisational routines of the project. Such associations expose connections between features of the interoperable IT and the organisational routines of the project and therefore provide a wide perspective from which the effects of interoperable IT on collaboration can be discussed. This allows a richer discussion of the advantages and capabilities of the technological operations based on the integrated data and corresponding implications on inter-disciplinary collaboration in design.

METHODOLOGY

The problem of investigating collaboration is complex because of the developing and dynamic nature of design work. The relations between the different design stakeholders and the design objects they are using are constantly changing, requiring the organisation to change in order to make collaboration possible. The structured and explicit nature of IT also gives it a false picture of the stability and certainty of the interactions in the project. A practice-based approach (Gherardi 2012) has been adopted in this paper as it allows both exploring the practice level, where sense-making occurs, and making associations between the practice and organisational levels. Moreover, the relational epistemology of a practice-based approach allows an explanation of the complex and evolving web of interactions between people and objects (including those mediated by IT) upon which the design collaboration is based (Gherardi 2012). Furthermore, the relational epistemology of practice-based studies acknowledges that the local (i.e. practices) and global (i.e. organisations) are connected.

The explanatory power of practice-based studies lies in their capability of establishing associations between these levels through zooming-in to the practices and zooming-out to the higher levels such as organisations (Nicolini 2012). The practice-based view presents phenomena that can be observed at higher levels of organisation as the effects of the web of inter-related practices at a lower level. This requires zooming-out, in the sense of observing the dominant discourses, discussions and tendencies within a field (Nicolini 2012). Here, the researcher interprets the collected empirical data through his/her understanding of the wider field. The rigour of such interpretations is ensured through the description of the local-global associations that are in line with empirical findings. In the case of construction design this requires looking at design objects (e.g. drawings) which change their roles in their interactions with people according to the situations they are used in (Ewenstein & Whyte 2009). This produces a definition of design collaboration as a practical accomplishment where people skilfully interact with design objects within a particular situation for development and communication of meanings.

The research uses empirical findings from a BIM enabled new built project in UK. This was an educational building project in its detailed design stage. In addition to the observational data collected from collaborative practices (i.e. design coordination meetings, model coordination and clash detection meetings etc.), open-ended interviews with design project stakeholders were also conducted in order to gain more insight regarding the collected data. The organisations involved did not allow the recording of these meetings but only attendance and interviews. Thus, data was recorded in field notes and the reflections on these were supported by the interviews. The findings will be presented in two sections. First the organisational environment of the project will be described with a particular focus on coordination activities in order to provide a basis for arguing about which activities were significant for the organisation to coordinate and how these were framed. Second, two events from practice will be presented to be interpreted through the lens of model and design interdependencies following Boyd (2013), who argued that studying events are useful for enabling a more holistic study of the adopted practices. Associations will be made between practice and organisational levels through the interpretations based on the insights from BIM and organisational studies literatures. These will allow hypothesising about some of the root causes of the challenges in collaboration in practice that are connected to the structure of interoperable IT and corresponding organisational effects and strategies.

LITERATURE REVIEW

A particular interest in this study is the recent literature on BIM and organising which introduces the problems of design collaboration. This will be followed by presentation of literature on technology, interdependencies and organising to establish a wider theoretical context that is used in the paper.

BIM and Design Collaboration

Empirical research into BIM and inter-disciplinary collaboration has paid particular attention to the organisational effects of interoperable IT for theorising about the effects of BIM on collaboration. Whyte and Lobo (2010) argue that digital integration of design data couples the different members of the design team closer; challenges the conventional boundaries between organisations, disciplines, teams and roles in the design project; and therefore work, involving the integrated data, needs to be highly regulated and formalised in order to be accountable. Nevertheless, they argue that although the interoperable software is set-up to be an integral part of the established formal control structure, control is never total, but rather boundaries, methods, objects and goals are negotiated (Whyte & Lobo 2010). In a similar line of thought, Dossick and Neff (2010) claim that BIM enabled projects with their closer technological coupling do not solve the inherent conflicts between different members of the design team, but make the boundaries more visible and harder to cross (Neff et al. 2010). This requires more leadership to make collaboration possible (Dossick & Neff 2010).

The interoperable IT assume a singular reality and so impose the rules codified in the technologies. Whyte (2013) shows the shortcomings of this for design in construction which has a future physical application. She argues that, in construction, designers cope with the complexities of the physical world through testing their design from multiple perspectives and interoperable IT is limited in these terms (e.g. designers benefited of using physical models in addition to information models) (Whyte 2013). She proposes open information systems for construction design work "in which an evolving and partial digital infrastructure can be used to achieve goals beyond the computer" (Whyte 2013). Neff et al. (2010) and Dossick and Neff (2011) argue that the centralisation and integration of design data produces over-determination and inflexibility in design and makes it harder to work in the inter-disciplinary design settings which require integration of multiple perspectives, knowledges, and standpoints. Dossick and Neff (2011) suggest that interoperable IT should be continuously complemented with informal communication to overcome this shortcoming. In a later article, Dossick and Neff (2014) particularly focus on documentation in BIM enabled design projects and argue that there is a cost attached to documentation in BIM enabled projects due to the fixity that is established by documentation of information in an integrated data repository. They claim that "the price of documentation include[s] an opportunity cost of unimagined solutions as well as the real cost of labour to modify models once developed" (Dossick & Neff 2014). In a similar fashion, Merschbrok and Wahid (2013) study task interdependencies, technological interdependencies and positions of stakeholders in the process chain in construction projects and conclude that in BIM enabled projects, due to the specific ways information is documented and integrated (i.e. forms and formats of information), those who are handed previously documented information are less flexible in their undertakings.

Finally, recent research into BIM and collaboration has also shown that there is a considerable ongoing joint effort of different design team members for the set-up and operation of interoperable IT as anticipated (Whyte 2011; 2013; Jaradat et al. 2013; Cidik et al. 2014). Whyte et al. (2015) argue that the rapid and flexible forms of project organisations, that were unlocked by interoperable IT, have limits in practice because of the lack of trust in the integrity of the information. Cidik et al. (2014) show that the efforts for the set-up and operation of interoperable IT include significant advance planning and documentation followed by ongoing negotiations and re-confirmations regarding the accountability of integrated data as a legitimate source of information. Whyte (2011; 2013) argues that working with interoperable IT requires undertaking processes outside of core design tasks making the success of an integrated technological infrastructure always fragile and only ever partly accomplished (Whyte 2013). Furthermore, Jaradat et al. (2013) claim that the ongoing efforts to keep the digital systems up and running became a central undertaking in the project and this created new roles and forms of accountability which were in conflict with historically established practices.

Technology, Interdependencies and Organising

Woodward (1965) and Perrow (1967) have argued that technologies are determinants of task structures which are essential for the establishment of organisational structures and therefore for communication and control structures. The same argument has been confirmed for IT in more recent studies with emphasis on the significant differences between the ways industrial and information technologies affect the organisational principles (Kallinikos 2006; Suchman 2007). Connected to these arguments, information technologies have been argued to have materiality (Leonardi 2010) due to the particular ways they affect practices as constraining, allowing, encouraging, facilitating, reminding, inviting etc. particular courses of action over the others. However, Suchman (2007) claims that such effects do not necessarily reflect the contingencies that should be addressed in the flow of practices because IT actions are fundamentally planned and therefore IT does not act with the unfolding social situations and their significances. Consequently, she conceptualizes information technology as an ordering object because of the rigid and planned structure of IT, the necessary organisational structures, with their communication and control mechanisms (Suchman 2007). In this respect, Luhmann (1993), and Lampel and Mintzberg (1996) argue that use of technology becomes a major control and efficiency strategy because of the need for keeping environmental variations to which technology cannot respond at minimum. They argue that this strategy is based on standardisation of work processes and outputs according to the standard ways of working of technological infrastructures (Luhmann 1993; Lampel & Mintzberg 1996). Furthermore, Weick (1990) argues that technology becomes a strategy for action and not just a tool; and so does not only affect practice-level activities of practitioners but also their understandings of the way work is organised.

Thompson (1967) has explained the relation between technology and organising through different types of task interdependencies created by different involvement of technologies in the performance of work. In his study, Thompson (1967) claims that technologies with different characteristics (in terms of the degree of standardisation of the inputs, transformation processes and outputs) create different types of task interdependencies that determine the kind of coordination required. Thompson (1967) argues that the organisational structure should be established based on these different task interdependencies that each requires different kinds of coordination.

Souza and Redmiles (2005) argue that there are many different definitions of interdependencies in the literature, but an overarching definition could be formulated as: “a relationship between two entities that exists because one must interact with the other to accomplish something ‘larger’ than the entities themselves”. Interdependencies have been studied from a number of different perspectives including interdependencies between tasks (e.g. Thompson 1967), parts of design products (e.g. Sosa et al. 2003), organisational parts (e.g. Sanchez & Mahoney 1996), technologies (Bailey et al. 2010) and their combinations (e.g. MacCormack et al. 2012) in order to analyse, relate and manage different frames of complexities inherent in organising. Souza and Redmiles (2005) claim that the idea of interdependencies stems from the assumption that complex systems can be decomposed into parts for making sense of, analysing and managing complexity. Decomposition creates parts and determines the interdependencies between these parts.

In line with this overarching definition, Bailey et al. (2010) define technological interdependence as “technologies’ interaction with and dependence on one another in the course of carrying out work”. Their study explores the effects of technological (in this case, IT that are used in service and knowledge work) interdependencies on organisations and suggests that coordination strategies of task and technological interdependencies are shaped by different considerations (Bailey et al. 2010). For example, they argue that, while in the case of task interdependencies it has been widely claimed that high interdependencies mean more need for coordination, in the case of technological interdependencies, coordination typically focuses on standardizing input and output. However, they also argue that integrating all separate technologies without considering larger occupational and organisational goals could disrupt beneficial, albeit time-consuming coordination efforts (Bailey et al. 2010).

An ongoing discussion around the interdependencies in the field of product design has been the relation between product model and organisational model (e.g. MacCormack et al. 2012). Sanchez and Mahoney (1996) claim that in product design processes, the structure of the product model and corresponding interdependencies create information structures that determine the suitable degrees of coupling between different organisational parts. However, Brusoni and Principe (2001) claim that the relations between product, organisational and knowledge interdependencies are not linear as they have different dynamics. In a similar line of thought, Henderson and Clark (1990) show that knowledge of an organisation is the result of an entangled yet precarious mobilisation of both product and organisational models. Therefore, even if the parts of the product do not change, changing the interdependencies between the parts can result in hardly recognisable and correctable destruction of useful knowledge which is embedded in the routine information procedures and organisational structures of the established organisations (Henderson & Clark 1990). Moreover, although correlations between product and organisational models have been reported (e.g. Frigant & Talbot 2005; MacCormack et al. 2012), Frigant and Talbot (2005) argue that the type, drivers and extent of this correlation are industry specific and need to be explored within the peculiarities of each industry.

Construction design has been studied from the lens of interdependencies and corresponding coordination strategies (e.g. Bølviken et al. 2010); however, studies particularly scrutinizing the role of IT mediation could not be found in this literature. Nevertheless, in a recent study, Knotten et al. (2015) reviews the design management literature from the perspective of interdependencies. In this study, Knotten et al. (2015) conclude that the types of interdependencies and significances of different types of interdependencies shift along the design process and therefore a dynamic approach to manage these is required. They further claim that the new design management approaches, such as BIM, should be reflectively calibrated for the management of various and shifting interdependencies, as they can be counterproductive otherwise (Knotten et al. 2015).

FINDINGS

In this section, two events from practice are described following a general description of the observed project and the coordination activities that took place in it. In the general description of the project and coordination activities, the focus is on the aspects of model coordination and clash detection meetings (MCMs) within which the observed events took place.

The observed project was a design & build educational new built project in which the main contractor undertook the main financial and design risk for the client. The project was ambitious in its use of BIM. At the outset, the project aimed to develop a fully coordinated model consisting of disciplinary models (e.g. an architectural model) with the purpose of using the design model as the baseline for further model-based cost management, scheduling, construction as well as for operation and maintenance purposes. The client had a BIM-literate estates team. Design team members also had working experience in BIM enabled projects as most of them had either worked in the previous phase of the observed project or in other BIM enabled projects. The project had detailed conventions for model based working (e.g. responsibility matrices for the objects in the model, naming conventions for object families etc.) as well as a detailed Employer's Information Requirements document describing the parameters for each of the objects in the model to be provided by specified stakeholders. This information was mainly documented under a BIM protocol which was part of the contract both for the main contractor and the designers. A commercial modelling platform (MP) that had architectural, mechanical-electrical-plumbing (MEP) engineering and structural engineering packages was chosen by the client to be used as the shared BIM platform (i.e. interoperable IT) in the project.

As part of a larger research project, data were collected from this design project mainly through observation of three main types of face-to-face coordination activities over a period of ten months during the detailed design stage. First, fortnightly design coordination meetings (DCM) were observed where specific coordination issues were discussed and general disciplinary updates were shared. Second, some coordination workshops were observed where a specific area of design was coordinated such as furniture and electrical engineering coordination. Third, MCMs were observed where mainly technical issues regarding model development and their extended implications on design were discussed.

Coordinating the Model in MCMs

MCMs were aimed to be held every month, however, they did not have a fixed interval and were mainly scheduled depending on the amount of development of the model since the previous meeting. This was to ensure that the model was meaningfully more developed than the one discussed in the previous meeting where clashes had been identified. In these meetings, two main types of discussions were observed. First, discussions about the implications of working with the model on design development and project management issues took place. This included discussions on the tolerances used in the information models, what was not modelled (i.e. anything below 1/50 scale was not modelled) and whose responsibility it was to coordinate this non-modelled information. Second, detected clashes and their relevance for the design were discussed in MCMs.

The differences between MCMs and other face-to-face coordination meetings were significant. First, the participants of MCMs were largely different from the ones who regularly participated in the DCMs and coordination workshops. Although, the same representatives of the architect attended all types of meetings, the representatives of the mechanical and electrical engineering (M&E) subcontractor and the structural engineer who attended MCMs were different.

Second, the vocabulary used in these meetings, and the strategies followed in order to deal with the issues, were considerably different from the other two types of meetings that were observed. In MCMs, the vocabulary used was very technology-centred with lots of terms adopted from design software and document management system such as objects, categories, worksets, models, names of different file formats, folders, clash detection rules etc. The strategies employed during these meetings were aimed at both understanding the technology and managing the technology for accomplishing the design tasks. The proper functioning of the interoperable IT was one of the main considerations during the discussions that took place in MCMs. This included negotiation of the procedures needed to be followed when working with the different information models, and how specific categories of objects could be turned off. These technology-centred discussions were not only focused on the design stage but also considered the use of the information model in the construction and operation stages. In the following, two events that took place in two different MCMs will be presented which demonstrate the different needs of the participants in the model and the capabilities of the model to work with what people wanted.

Event 1:

In the MCM where this event happened, the architect stated that they needed lighting in the M&E model in order to coordinate the suspended ceilings. Following this, the modelling manager of the M&E subcontractor stated that they had taken the decision to model the lighting last. The design manager of the main contractor supported the architect and stated that they had agreed that the M&E subcontractor would model the lighting at this stage. The modelling manager of the M&E subcontractor argued that they previously put considerable effort into modelling the lights at the atrium area and then when the hosting objects were deleted in the architectural model the whole effort was wasted and therefore they decided to model the lights last when the coordination and decisions around the lightings were completed. He argued that the coordination had previously been done by overlaying 2D drawings on the architectural model and this could done like this again. Following this, the architect and the design manager objected to his argument. In response to this, the representative of the M&E subcontractor explained in an upset fashion, that the modelling platform (MP) that was imposed by the client was not geared up for M&E services and they had already needed to create half of the objects including switches, plugs etc. He continued that they had modelled all the equipment in other software where it was much easier to model but exporting it to the MP was problematic. He further argued that his colleagues on the site who were responsible for the installations asked for the systems to be modelled as closed systems with all the elements connected to each other in the information models in order to make sure that the system calculations and design were adequate and finalised. He added that the MP took almost one minute after each and every single change when working with connected and closed systems as the computer needed to re-calculate the whole system again and this made the MP even harder to use efficiently. Moreover, he argued that automated connections between different elements of the system could be wrong and unintentional many times in the MP. Although the design manager of the main contractor added that they did not need closed system in the model and just the geometry of M&E system was enough for their coordination purposes, this was in contrast with the general expectation within the project to use the MP as a full design development tool. At the conclusion of the discussion, the modelling manager of the M&E subcontractor told the architect in a calmer voice that they could not provide all the required items in the model in such a short time; but, they could adjust their modelling priorities to the needs of other stakeholders.

Later on in the project, when the ceilings started to be installed on the site, the suspended ceilings needed to be re-documented in a number of 2D drawings with a much finer level of detail and measurements from the site because the installation tolerances on the site made the modelled setting-out details irrelevant.

Event 2:

In the observed project, there was a constant struggle to benefit from automated clash detection. The main challenge was to differentiate between the clashes that resulted from real design problems and the ones that resulted just from poor modelling among the thousands of clashes detected by the MP. The main strategy for handling this was to filter the list of clashes according to the categories of objects and strategically choosing the categories that were more likely to clash because of real design problems rather than the non-detailed modelling due to time constraints. For example, the model identified clashes between the screed on the slab and the structural columns, however, this was marked as "approved" so that it could be neglected in future clash detection exercises because everyone would know that the columns would be in their place well before the application of the screed. Thus, in this context, the ideal of a clash-free model did not mean a model without clashes but rather meant a model with managed clashes. Such a strategy required strictly following naming conventions in the model and also setting up further clash detection rules in the software. However, defining more and detailed rules was not found beneficial as with each new rule added there was an exponential increase in the number of clashes detected. Another implicit strategy was to look for unusually large or low numbers of detected clashes under the filtered categories. In such cases, first the underlying technological causes were questioned (e.g. turned on/off clash detection rules, versions of the uploaded information models etc.). The overwhelming number of detected clashes and uncertainty about the underlying reasons caused tensions during clash detection exercises. On the one hand, the criticisms of the representative of the client and the design manager of the main contractor about the high numbers of clashes were not well received by the designers who were supposed to both develop the design in an iterative way and model the information in clash managed ways. At the same time, the client representative and the design manager of the main contractor kept stating that a clash-free model did not mean a really clash free construction and it was still the responsibility of the designers to coordinate the design with the ultimate aim of having a clash-free design.

In the meeting where this event happened, the architect was criticised for having too many in-discipline clashes between the furniture and internal wall categories which were both owned by the architect. The unexpectedly high number of clashes created a sense of disturbance in the team. The architect claimed that he was aware of these clashes and these did not need to be picked up at that moment because the locations of most of the furniture were not finalised and therefore the architects did not seek to model them clash-free. The design manager of the main contractor further criticised him saying that, then, he should not have exported unfinished worksets for clash detection. The architect objected to this by saying that although clashes between furniture with internal walls were not relevant at that stage; they needed to check for the clashes between some of the fixed furniture with other disciplines' objects. The architect further stated in an upset fashion that if on site there was an in-discipline clash due to their poor modelling they would be ready to pay for the extra cost and then started to question the purposes of model based design. He criticised the critiques regarding their in-discipline clashes which he thought were normal to have at that stage of the design. As an answer to the architect's statement, the design manager of the main contractor stated that the model was not only a disciplinary document but would also be used for construction and operations and therefore the targets and procedures in place needed to be followed to satisfy multiple requirements from the digital model.

DISCUSSION

There is a growing awareness that the problematic nature of collaboration in construction design projects is further complicated by the use of interoperable IT. Consequently, there is a need to investigate the ways interoperable IT intervene in the inter-disciplinary relations and affect mutual engagement of different design members. A distinction is drawn here between the "model interdependencies" and the "design interdependencies" in order to create a frame of reference that can separate technology related and design task considerations. Digital integration of data is based upon standardised inputs and rule based connection of data from different designers. Consequently, for the interoperability of IT, user-software interactions need to be structured according to i) the pre-defined ways in which the digital integration operates and; ii) common interaction conventions that need to be established among the users. These requirements create "model interdependencies" that need to be considered by design team members for keeping the IT interoperability up, running and capable of delivering the expected efficiencies (e.g. automated clash detection). However, the design has been perceived, judged and developed by design team members from a great variety of perspectives which are not always in line with or represented by the model interdependencies. In this context, effects of working in a technologically integrated environment are discussed by looking at the interdependencies raised as part of working with the digitally integrated data (i.e. model interdependencies) and other design related interdependencies (i.e. design interdependencies). Technological interdependencies have been previously studied in terms of the interdependencies between separate technologies (Bailey et al 2010; Merschbrok & Wahid 2013). However, in this paper, the term "model interdependencies" is used with a more focused meaning which is limited to the interdependencies as a result of the rule based digital integration of design data.

Both events exposed some model interdependencies that needed to be created and committed to in order to realise some potential advantages of digital integration of design data. In the first event, there were two expected advantages from model based integration of data. The first was better geometrical coordination of ceilings through digital integration of M&E and architectural designs. The second was more accurate and precise M&E system design through the development of the system in the model as a closed system where all parts of the system were digitally related by the modelling software. Model based coordination of ceilings meant model interdependencies between M&E lighting design and architectural ceiling design. However the modelling manager of the M&E subcontractor pointed out the downside of such interdependencies drawing on the event when the ceilings in the atrium (as hosting objects) were deleted by the architect and their effort of modelling was wasted. Moreover, modelling M&E systems as closed systems created model interdependencies between different elements of the modelled system, which in turn resulted in poor computational performance and unintentional automated connections made by the software. Consequently, in practice, due to the perceived "price of documentation" (Dossick & Neff 2014), the modelling manager of the M&E subcontractor was reluctant to use MP as the primary design tool. Additionally, this phenomenon, overall, hindered the timely coordination of basic design interdependency for the coordination of lighting in ceilings. Thus, trying to achieve the perceived benefits of having more precise, accurate and developed information models meant creating more model interdependencies and additional work. However, the expected benefits became even more questionable when the ceilings started to be installed on the site as the installation tolerances required made the detail in the model irrelevant.

In the second event, automated clash detection was based on checking the connections that the software established between different entities in the model (i.e. model interdependencies) against pre-defined rules. However, in practice this needed to be managed by people by filtering thousands of clashes through the object categories used in the model and deciding on the correct detail of the detection rules etc. In other words, the automated detection exercise based on the model interdependencies needed to be reworked as some of the detected clashes were negligible (e.g. just poor modelling) and others were controversial with design interdependencies. For example, the need for clash detecting the fixed furniture with other disciplines without exporting the whole furniture category, which was not completed at the time, caused a conflict between modelling and design interdependencies. The tensions caused by such cases resulted in questioning the purposes of model based working and what should be valued over others. As stated by Jaradat et al. (2013), in such situations it became "increasingly difficult to rely on institutionalized assumptions about who does what, whose view could override others, and who is responsible for what".

The findings suggest that the model interdependencies that were created as a result of working with the integrated data were not always supportive for all members of the project team in their undertakings and caused tensions. The requirements of working with integrated data for realising some expected benefits of the interoperable IT (e.g. error-free calculated closed M&E systems, clash-free model etc.) conflicted with some other considerations of designers. However, resolution of these problems through modifying the IT was largely not possible as the expected efficiency gains of IT were fundamentally based on the controlled and standardised inputs, operations and outputs of the interoperable IT. Previous research into BIM and organising has stated that the effects of digital integration of design data were subject to negotiations between design stakeholders to be settled in practices and enable collaboration (e.g. Whyte & Lobo 2010; Dossick & Neff 2011). This argument is extended here as, although the perceptions of design team members regarding the capabilities of the interoperable IT were shaped through these ongoing negotiations, the interactions between designers and interoperable IT could hardly be modified. The fundamental rigid requirements of interoperable IT and corresponding perceived advantages as a formal control mechanism (especially by the powerful actors such as the main contractor) left limited space for its "appropriation" (Salovaara et al. 2011) through negotiations. Consequently, although practices and interoperable IT mutually shaped each other, this mutual shaping was asymmetrical.

This argument also points to a difference from the findings of Bailey et al. (2010). In line with Bailey et al. (2010), in the observed project, the typical strategy for coordinating the technological (model) interdependencies was the standardisation of inputs and outputs. However, different from Bailey et al. (2010), this research studied an inter-organisational setting and in this setting, consideration of organisational and occupational goals (design interdependencies) in the strategic management of technological (model) interdependencies was limited. Additionally, in this research, conflicts between technological (model) interdependencies and occupational / organisational (design) interdependencies were observed. Even in these cases, conflict resolution through appropriation of IT according to occupational goals was mostly not possible. This in turn mostly led the designers to adjust their working according to the requirements of the interoperable IT.

As argued by Knotten et al. (2015), design management requires coordination of various inter-related considerations with changing effects and significances over the course of the project. In the observed project, the model interdependencies established complex relationships between historically generated design interdependencies and made coordination requirements for the interdependencies harder to grasp and manage in this new situation. It has been found that the know-how of practitioners regarding what to coordinate, why and how, was based on historically established practices and the interdependencies rooted in them. The complex relations between model and design interdependencies made this know-how of inter-disciplinary collaboration irrelevant in this new situation and caused confusions and conflicts. Such confusion was evident in Event 2 when the architect started to question the purpose of the model based working after the criticisms regarding the high number of architectural in-discipline clashes.

This argument is in line with previous studies where it was argued that product, organisational and knowledge interdependencies cannot be linearly mapped (Brusoni & Principe 2001) into simple and unique parts (e.g. M & E systems, architectural systems etc.). The changing interdependencies caused by the introduction of IT suppress useful know-how for skilful recombination of the parts (Henderson & Clark 1990). This previously established know-how was embedded in the previous organisational structure and its routine procedures (Henderson & Clark 1990). In this new situation, the design team members struggled to make sense of the significances of the conflicting requirements and to articulate what should be coordinated and why?

It can be claimed that the industry will eventually develop optimised ways of dealing with interdependencies in this new situation considering both technological and design collaboration requirements in a balanced way (e.g. open systems as proposed by Whyte 2013), thus, enabling interoperable IT supported enhanced collaboration. However this cannot be taken for granted as our findings show that, in practice, conflicting considerations between model and design interdependencies have not always been resolved through negotiated reconciliation but at times were subject to domination of one by the other according to the situations and actors involved. For example, the client's and the main contractor's power positions and their control focused roles over the design made the agenda of keeping the integrated data up and running favourable because of the capabilities of IT mediation as a control strategy. As a result of this, at organisational level, segregation of model related and design development related practices were observed in the project: separate model related meetings, different vocabularies that dominated these meetings, separate model related roles and considerations, separate coordination strategies for the modelled elements and those that were not modelled were present. Consequently, an awareness of this segregation and necessary social and technological precautions are required in order to integrate the efforts of different members of the design team in a complementary way and achieve better design collaboration.

CONCLUSION

There has been a growing awareness that design collaboration has been made more complicated with the use of interoperable IT in BIM enabled projects. This paper has investigated the way interoperable IT intervene in inter-disciplinary relations and affect mutual engagement of different design members. This paper contributes to the research into BIM and collaboration in two ways.

First, it showed that making the distinction between model interdependencies and design interdependencies provides a useful frame of reference for dealing with the complexity of the phenomena. This not only critically questioned the capabilities of IT to mediate in design collaboration but also provided a rich discussion about the incorporation of technology and organising. Further research needs to refine this approach and critically conceptualise model and design interdependencies for using them further for richer analyses.

Second, it extended the understanding of the effects of BIM on collaboration. It was argued that technological considerations and other design related considerations can be in conflict and that the resolution of these conflicts may not be easily achieved due to the fundamental characteristics of interoperable IT and the ways it is framed by powerful actors. Furthermore, historically established know-how for collaboration has been made irrelevant in the changes that take place due to the interdependencies in BIM enabled design projects. At the organisational level, these effects cause a segregation of the organisation into model related practices and design development practices which works against collaboration. Thus, if better design collaboration is actually to be achieved, this segregation needs to be managed and necessary social and technological precautions need to be taken in order to integrate the efforts of different members of the design team in a complementary way.

REFERENCES

Bailey, D.E., Leonardi, P.M. and Chong, J., (2010) "Minding the Gaps:Understanding Technology Interdependence and Coordination in Knowledge Work," *Organization Science*, 21(3), 713–30.

Bølviken, T., Gullbrekken, B. and Nyseth, K., (2010) "Collaborative Design Management," In: *Proceedings of the IGLC-18*, Technion, Haifa, Israel.

Boyd, D., (2013) "Using Events To Connect Thinking And Doing In Construction Management," *Construction Management and Economics*, 31(11), 1144-59.

Brusoni, S. and Prencipe, A., (2001) "Unpacking The Black Box Of Modularity: Technologies, Products And Organizations," *Industrial and Corporate Change*, 10(1), 179-205.

Cidik, M.S., Boyd, D. and Thurairajah, N., (2014) "Leveraging Collaboration Through The Use Of Building Information Models," In: Raiden, A. and Aboagye-Nimo, E. (eds.), *Proceedings 30th Annual ARCOM Conference*, 1-3 September 2014, Portsmouth, UK, 713–22.

Dossick, C.S. and Neff, G., (2010) “Organizational Divisions In BIM-Enabled Commercial Construction,” *Journal of Construction Engineering and Management*, 136(4), 459-67.

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.

Dossick, C.S. and Neff, G., (2014) “Interpretive Flexibility and the Price of Documentation,” In: Chan, P. and Leicht, R. (eds.) *Proceedings of Engineering Project Organization Conference 2014*, 29-31 July 2014, Colorado, USA.

Ewenstein, B. and Whyte, J., (2009) “Knowledge Practices In Design: The Role Of Visual Representations As 'Epistemic Objects',” *Organization Studies*, 30(1), 7-30.

Frigant, V. and Talbot, D., (2005) “Technological Determinism And Modularity:Lessons From A Comparison Between Aircraft And Auto Industries In Europe”, *Industry and Innovation*, 12(3), 337-55.

Gherardi, S., (2012) “*How To Conduct A Practice-Based Study*,” Cheltenham, UK: Edward Elgar Publishing Limited.

Henderson, R.M. and Clark, K.B., (1990) “Architectural Innovation: The Reconfiguration Of Existing Product Technologies And The Failure Of Established Firms,” *Administrative Science Quarterly*, 35(1), 9-30.

Ide, N. and Pustejovsky, J., (2010) “What Does Interoperability Mean, Anyway? Toward an Operational Definition of Interoperability,” In: *Proceedings of the Second International Conference on Global Interoperability for Language Resources, ICGL 2010*, Hong Kong, China.

Jaradat, S., Whyte, J. and Luck, R., (2013) “Professionalism In Digitally-Mediated Project Work,” *Building Research & Information*, 41(1), 51-59.

Kallinikos, J., (2006) The consequences of information. Cheltenham, UK: Edward Elgar Publishing Ltd.

Knotten, V., Svalestuen, F., Hansen, G.K. and Lædre, O., (2015) “Design Management In The Building Process - A Review Of Current Literature,” *Procedia Economics and Finance*, 21, 120-127.

Lampel, J. and Mintzberg, H., (1996) “Customizing customization,” *Sloan Management Review*, Fall: 21-30.

Leonardi, P.M., (2010) “Digital Materiality? How Artifacts Without Matter, Matter,” *First Monday*, 15 (6-7). Available at: <http://firstmonday.org/ojs/index.php/fm/article/view/3036/2567>. [Accessed 29 March 2015].

Luhmann, N., (1993) “*Risk: A Sociological Theory,”* Berlin, Germany: De Gruyter.

MacCormack, A., Baldwin, C. and Rusnak, J., (2012) “Exploring The Duality Between Product And Organizational Architectures: A Test Of The “Mirroring” Hypothesis,” *Research Policy*, 41, 1309–24.

Merschbrock, C. and Wahid, F., (2013) "Actors' Freedom of Enactment in a Loosely Coupled System: The Use of Building Information Modelling in Construction Projects," In: *Proceedings of ECIS 2013*, paper 107. Available at: < http://aisel.aisnet.org/cgi/viewcontent.cgi?article=1330&context=ecis2013_cr>. [Accessed 29 March 2015].

Neff, G., Fiore-Silfvast, B. and Dossick, C.S., (2010) “A Case Study Of The Failure Of Digital Communication To Cross Knowledge Boundaries In Virtual Construction,” *Information, Communication & Society*, 13(4), 556-73.

Nicolini, D., (2012) “*Practice Theory, Work, & Organization*,” Oxford, UK: Oxford University Press.

Perrow, C., (1967) “A framework for the comparative analysis of organizations,” *American Sociological Review*, 32(2), 194-208.

Salovaara, A., Höök, K., Cheverst, K., Twidale, M., Chalmers, M., and Sas, C., (2011) “Appropriation And Creative Use: Linking User Studies And Design,” In: *Proceedings of CHI '11 Extended Abstracts on Human Factors in Computing Systems*, ACM, 37-40.

Sanchez, R. and Mahoney, J.T., (1996) “Modularity, Flexibility, And Knowledge Management In Product And Organization Design,” *Strategic Management Journal*, 17(S2), 63-76.

Sosa, M.E., Eppinger, S.D. and Rowles, C.M., (2003) "Identifying Modular And Integrative Systems And Their Impact On Design Team Interactions," *ASME Journal of Mechanical Design*, 125, 240-52.

Souza, C.d. and Redmiles, D., (2005) "An Interdisciplinary Perspective on Interdependencies," Institute for Software Research, University of California, Irvine, Technical Report UCI-ISR-05-7.

Suchman, L.A., (2007) “*Human-Machine Reconfigurations: Plans And Situated Actions*,” Cambridge, UK: Cambridge University Press.

Thompson, J.D., (1967) “*Organizations In Action*,” New York: McGraw-Hill.

UK 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 22 March 2015].

Weick, K.E., (1990) “Technology As Equivoque: Sensemaking In New Technologies,” In: Goodman, P.S., Sproull, L.S. and Associates (eds.) *Technology and Organizations*, 1-44.

Whyte, J. and Lobo, S., (2010) “Coordination And Control In Project-Based Work: Digital Objects And Infrastructures For Delivery,” *Construction Management and Economics*, 28(6), 557-67.

Whyte, J., (2011) “Managing Digital Coordination Of Design:Emerging Hybrid Practices In An Institutionalized Project Setting,” *Engineering Project Organization Journal*, 1(3), 159-68.

Whyte, J., (2013) “Beyond The Computer: Changing Medium From Digital To Physical,” *Information and Organization*, 23(1), 41-57.

Whyte, J., Stasis, A. and Lindkvist, C. (2015) “Managing Change In Complex Projects: Configuration Management, Asset Information And Big Data,” *International Journal of Project Management*, (In Press).

Woodward, J., (1965) “*Industrial Organization: Theory And Practice*,” New York, NY: Oxford University Press.