EXPLORING THE DYNAMIC SOCIAL INTERACTIONS THAT UNDERPIN WORK HEALTH AND SAFETY RELATED DESIGN DECISION-MAKING

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The proactive practice of anticipating and 'designing out' work health and safety (WHS) risks at early project stages, known as Safety in Design, is well-recognised. Previous research also suggests that the effective interaction between design and construction participants is vital to make construction process knowledge accessible to design decision-makers. Nevertheless, effective communication still seems to be a problem in practice. A PhD study is underway to explore the impact of interactions between design and construction decision-makers on the quality of design decisions and WHS outcomes. Social network analysis (SNA) is recommended as a useful tool to explore the patterns of interaction between project participants. Previous applications of SNA in construction have largely been cross-sectional and single-level in their focus, implicitly assuming a degree of stability in the project context. The reality is, however, that the construction project context is unpredictable. Decisions unfold and trade-offs are made at different organisational levels as participants negotiate solutions to emergent problems. The identity, role and influence of project participants also change over time. Thus, the longitudinal and multilevel applications of SNA may be better suited to investigate the complex and dynamic patterns of interaction that underpin design decisions. In this paper, the research rationale is explained and a methodological discussion is put forward.

Keywords: social network analysis, dynamic interaction, decision-making, H&S

INTRODUCTION

The prevalence of accidents and injuries in the construction industry is problematic due to the financial, psychological and productivity burdens created for individuals, organisations and the whole industry. Traditionally, construction firms have been solely held responsible for on-site work health and safety (WHS). However, during the past two decades, there has been a growing recognition that the root causes of WHS incidents on construction sites can be traced back to problems inherent in systems of work conceived in the early lifecycle of construction projects (e.g. planning and design stages). Consequently, the proactive practice of anticipating and 'designing out' WHS risks at early project stages, referred to as Safety in Design (SiD), has gained recognition and has become a key feature of WHS legislation and policies in some countries, for example Construction Design and Management Regulations 2015 in the UK and the current model WHS regulations which has become a requirement in most of the states in Australia. In

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addition, a growing number of construction companies have included SiD processes as part of their safety management and risk management procedures.

In line with these initiatives, research has been conducted in relation to the effective implementation of SiD. In particular, the organisational and contractual separation of the design and construction functions in construction projects has been identified as a problem because free and effective flow of communication between constructors and designers is not always possible. Recent research (Lingard *et al*., 2014a) has provided evidence that positive WHS outcomes are facilitated through the integration of construction process knowledge into design decision-making about the permanent features of a building or facility.

Furthermore, research has concluded that the timing of making WHS related decisions is also important in construction projects and that early consideration of WHS in project decision-making can lead to the implementation of more effective methods of risk control during construction (Lingard *et al*., 2015). Despite the growing momentum surrounding safety in design (SiD), research has provided evidence that in many cases designing for WHS has achieved suboptimal results in the construction industry (Gambatese *et al*., 2005). In fact, in many cases, the implementation of SiD has been limited to deliver modest reductions in WHS risks rather than eliminating inherently dangerous activities (Atkinson and Westall, 2010). Studies have proposed a number of factors contributing to successful implementation of SiD including designers' knowledge and attitude towards the concept (Gambatese *et al*., 2005), clients' motivation and commitment and involvement of contractor (Goh and Chua, 2016). Nevertheless, an important underlying issue, which remains unresolved, is that the efforts to improve WHS at design stage in construction have failed to acknowledge and cope with the special characteristics of the design process (Lingard *et al*., 2014b).

DESIGN DECISION MAKING IN CONSTRUCTION PROJECTS

Construction design is a complex process. Lingard *et al*., (2012) classify the complexity inherent in the design process into two categories: organisational complexity and technological complexity. The organisational complexity stems from a significant division of tasks, involvement of multiple specializations and many interdependencies between organisational elements at different hierarchical levels (Lingard *et al*., 2012). In fact, design teams are referred to as 'temporary, multidisciplinary and network-based organisations' (den Otter and Emmitt, 2008). The technological complexity of the design process, on the other hand, arises from the involvement of a network of tasks, requiring contributions from multiple specialists, and a high level of interdependency between technologies, tasks or inputs (Lingard *et al*., 2012). In fact, design outcomes emerge from a network of inter-related decisions made through repeated interactions between multiple stakeholders. These interactions, in turn, form a complex structure of information exchanges supporting the design decision-making process.

Design is a multi-disciplinary process. As a result of the high complexity in modern construction methods and techniques, the design and construction processes have progressively become more specialised. This specialisation has increased the number of participant organisations and individuals with design responsibility (Austin *et al*., 2007). Often, the required knowledge to make design decisions resides in more than one design participant (Pektaş *et al*., 2006). Consequently, the timely and effective exchange of information between participants is critical for completion of design tasks and to ensure that components are compatible (Gray *et al*., 1994). Design process is dynamic and collaborative. Tryggestad *et al*., (2010) view construction design work as a collective activity characterized by social negotiations among coalitions of parties and distributed knowledge production. As they have also revealed, design involves a continuous process of (re)design activities to accommodate transforming interests of participants. Design goals are not invariant inputs established at the outset of a project which remain unchanged. Rather, design goals evolve through a flexible process of revisiting ambitions and engaging in 'trade-offs' to find practicable solutions to emergent problems (Tryggestad *et al*., 2010).

Iteration is a typical characteristic of the construction design process. Iteration implies refinement and is usually required for two reasons: 1) an unexpected failure to meet design requirements, 2) a response to the late availability of new information (Pektaş *et al*., 2006). Minimising unexpected iterations is desired in design management. One way of achieving this is to improve information quality and reduce uncertainty in decision-making through timely supply of information and involvement of appropriate participants in the design process. In addition, faster iterations (fewer amount of rework) are achievable by improved coordination of design activities (Pektaş *et al*., 2006).

The interdependency inherent in construction design is indicated in research by Austin *et al*., (2000) who report that a typical building design process can comprise between seven and 12 iterative loops. Each of these iterative loops consists of between five and 30 interrelated tasks. They also examined the design process of a hospital project and identified around 800 tasks and 10,000 information dependencies. Looking at specific phases in design, Austin *et al*., (2001) found high interdependency within and across activities in the conceptual design of a single building element. They also identified 'the process of social interaction' (i.e. the transfer of information, opinion and ideas) between design team members as a critical component of conceptual design activity.

Research has also revealed the roles that different groups of participants play in shaping design decisions. Particularly, suppliers and specialist subcontractors have been recognised for demonstrating innovative and independent decision-making in the design and manufacture of specialized building components (Lingard *et al*., 2012). Indeed, there is a growing recognition that modern building design is a collective and interactive process which involves complex and dynamic interdependencies between activities and among participants, and is thus best undertaken collaboratively.

INTEGRATING DESIGN AND CONSTRUCTION DECISIONS

Research in construction has identified considerable benefits in the integration of construction expertise and knowledge into early project decision-making. (See e.g Song *et al*., 2009). Improved constructability and WHS have been mentioned frequently as one of these benefits (Gambatese, 2000; Lingard *et al*., 2014a). Consequently, it has been proposed that improvements in WHS require more integrated approaches to WHS decision-making which are supported by early-stage collaboration and effective interaction within and between two groups of project participants:

- those involved in early planning and designing the final product (i.e. building, structure, and facility), and
- those involved in making decisions about the construction process.

The collaborative design development is the basis for building sustaining relationships that accommodate complexity and reduce uncertainty (Austin *et al*., 2007). Through collaboration, knowledge and information can be shared between project participants and there would be less reliance on inaccurate assumptions. This is particularly important in relation to SiD, which involves knowledge from two main areas, the design of the final product and the design of construction process. A main issue identified by researchers is that design professionals in the construction industry mostly possess limited knowledge of construction and maintenance processes (Gambatese *et al*., 2005). This is partly because design professionals have traditionally focussed on the requirements of end users of a facility or building rather than those who undertake the construction and maintenance works (Hecker and Gambatese, 2003). As Lingard *et al*., (2014b) suggest, the problems can be overcome by ensuring that:

- a genuine lifecycle approach to safety is adopted in design; and
- design decisions are informed by construction [and WHS] knowledge [through collaboration].

Effective interaction between project participants involved in the design and construction stages of construction projects has great potential to facilitate collaboration and address the knowledge gaps mentioned above; however, in practice, the organisational and contractual separation of the design and construction functions acts as an impediment to freely and effectively flowing communication (Lingard *et al*., 2014b; Atkinson and Westall, 2010) and can negatively influence desired outcomes including those related to WHS (Baiden and Price, 2011). Despite this acknowledgement, few empirical studies have explored how to achieve improved WHS outcomes by addressing the segregation and communication problems in construction projects. Hare *et al*., (2006) cite several mechanisms that substantially assist with integrating WHS into project planning and design decision making:

- two-way communication between designers and constructors;
- the early involvement of the constructor;
- participation in health and safety workshops; and
- collaborative brainstorming.

Franz *et al*., (2013) have presented case study data suggesting that in comparable projects, better WHS outcomes are achieved when specialist contractors are involved early. Improved constructability is often claimed to result from collaborative or integrated approaches to project delivery and that, by implication, WHS is also enhanced (Kent and Becerik-Gerber, 2010). However, some researchers caution that the implied link is not straightforward:

- Ankrah *et al*., (2009) observe that the procurement method will not generate, as a matter of course, a positive cultural orientation to WHS;
- Atkinson and Westall (2010) point out that Integrated Project Delivery does not guarantee improved safety outcomes.

To sum up, an existing challenge in relation to the implementation of SiD in the construction industry is that, in most cases, there is not enough collaboration and effective communication to support the effective integration of design and construction decision-making. Even in cases that systems and processes have been put in place to facilitate collaboration and communication, they have failed to cope with the complex and dynamic nature of the design process. Therefore, it is suggested that to better exploit the WHS improvements intended by SiD, there is a need to understand and find ways to enhance communication and collaboration in the complex and dynamic context of construction projects. This understanding and enhancement effort should be based on the acknowledgement and acceptance of the special characteristics of the construction design process, i.e. the complex, dynamic and collective nature of design decision-making.

UNDERSTANDING SOCIAL INTERACTIONS IN PROJECTS

Construction projects involve social activities. Project participants normally come together from different firms. They possess diverse knowledge and expertise and interact to make decisions about various aspects of the project and deliver a set of tasks that contribute to the achievement of the overall project goals. The patterns of interactions and relationships between project participants are important in terms of understanding how project organisations function (Pryke, 2012). The project interactions can be conceptualised as social networks. According to Pryke and Smyth (2006), through these networks, individuals who are engaged in different project functions (e.g. planning, design, construction) communicate in relation to their project roles and responsibilities and establish a sense of 'mutual understanding' about terminology, values and priorities.

Social networks exist at multiple levels of project organisation. They create the substructure that supports different project functions at various levels. Pryke (2012) observes that project participants are embedded in multi-layered transitory networks of relationships that relate to project functions. At the lowest level, individuals with project-related responsibilities exchange information with other individuals both from the same firm and from external firms. The networks constantly change. Due to the diverse set of circumstances and different knowledge combinations and expertise required to perform various tasks, the interaction networks continually reconfigure, enabling the project participants to deal with the multitude of complex activities involved in executing a project (Pryke and Smyth, 2006).

The networks of interactions are particularly important in relation to design decision-making. Austin *et al*., (2007) suggest that collaborative design needs an easy flow of information between all parties outside the rigid structures forced by contractual arrangements. To reduce the unexpected impacts, assumptions in relation to early design aspects need to be more accurate and/or enough tolerances should be considered to accommodate future changes. This, in turn, requires collaboration and effective communication to make the right information available to the right participants at the right time (Pektaş *et al*., 2006).

According to Chinowsky *et al*., (2011), an effective level of exchange between parties involve the exchange of both explicit and tacit knowledge to resolve inter-task issues as they arise; however, the unstable context of construction projects and insufficient past working interactions between parties create challenges for effective collaboration. This has mostly directed project team efforts to build [reactive] communication networks that are efficient in meeting particular project needs, but may lack the characteristics of an effective network (Chinowsky *et al*., 2011). Pirzadeh and Lingard (2017) suggest that project leadership teams can benefit from continuously mapping interaction networks and understanding how they change and play out to produce project outcomes. This understanding can assist project teams to proactively design, encourage and maintain networks that are more likely to support effective decision making and performance.

Social-network analysis (SNA) is proposed as a practical method to map and analyse relationships and interactions. SNA is an analytical tool to visualise and study the patterns of relationships and the exchange of resources (e.g. knowledge, information) among participants in a network. In the construction context, SNA has been applied in the analysis of relationships, information exchanges and communication patterns between project participants (both at individuals and organisational levels). SNA has been recommended as a useful method for understanding the roles and quantifying the interactions of participants in construction project coalitions. Social network characteristics have been used to conceptualise construction project coalitions and to compare project procurement and governance systems (Pryke, 2012), to explain poor performance in team-based design tasks (Chinowsky *et al*., 2008), and to identify barriers to collaboration that arise as a result of functional or geographic segregation in construction organisations (Chinowsky *et al*., 2010). The technique has been used, in combination with task dependency analysis, to identify potential communication disconnections between project participants (Chinowsky *et al*., 2011). Park *et al*., (2010) used SNA to study inter-firm collaboration in the construction industry and its effect on organisational performance. SNA has also been used to analyse knowledge flows among construction project participants during the design variation process (Ruan *et al*., 2012). In addition, Lingard *et al*., (2014a) used SNA to map and analyse the pattern and nature of communication between participants in WHS related design decision-making in construction projects and found a link between social network measures and WHS performance.

So far, the applications of social network analysis in construction projects have been mostly one-off and cross-sectional, implicitly assuming a static and lasting pattern of interactions between project participants. In a classic fashion, the technique has mostly been used to analyse 'static' or 'aggregated' networks (Tang *et al*., 2009) by taking a snapshot of the social interactions at a particular point in time or to aggregate the social interactions over a period of time, e.g. over the whole project duration, to create an overall view of the social network. As such, this approach assumes some level of stability in a project social network over time. This assumption might be valid for short periods of time; however, its validity is questionable over long time spans due to the dynamic context of construction projects. The reality is that while the formal structure of a project organisation might remain stable throughout the project for contractual reasons, the configuration of participant's changes as they assume different roles for dealing with different activities at various organisational levels (Pryke and Smyth, 2006).

THE NEED FOR A LONGITUDINAL AND MULTI-LEVEL NETWORK APPROACH

In the context of SiD, although collaboration and effective communication have been emphasised as a requirement for the effective implementation of SiD, few studies have actually delved into the nature of communication and collaboration in relation to SiD decision-making as it happens in the real complex and dynamic context of the construction design process. Firstly, despite recognizing the networked nature of relationships and interactions in construction projects, there are few studies that have taken a network perspective to observe collective interactions and negotiations in live projects as design decisions unfold and participants' roles and interests change (examples of using network perspective are Tryggestad *et al*., 2010; Lingard *et al*., 2012).

In the context of construction WHS, the application of SNA has shown that effective interaction between those involved in the design of the structure (building or facility) and the construction process is linked to improved WHS outcomes (Lingard *et al*., 2014a). Nevertheless, these applications have mostly been cross-sectional, and as such, have not taken into account that networks are dynamic and evolve over time. By taking a snapshot of the social network or by aggregating the social interactions over periods of time (e.g. normally over the whole project) these studies have assumed a static and lasting pattern of interactions between project participants. Using this approach, the social network data has often been collected retrospectively, by asking participants their recollections about project interactions and communication patterns during the project. This approach assumes a level of stability in social network over time, thus does not appreciate the complexity and dynamism of the construction project context. In fact, recent applications of SNA to study the properties of human interactions have identified that the time dimension of interactions is usually a 'neglected' or 'understated' factor (Tang *et al*., 2009). Consequently, there is a requirement for longitudinal studies of relationship and interaction networks (in relation to construction WHS) that take into account the dynamism of project context.

Secondly, where network-based methods have been used to observe relationships and interactions in relation to project outcomes, the link between network measures and project outcomes is not clearly explored and established. Most of these studies refer to the coexistence (correlation) of particular network patterns/measures and specific outcomes and consider this coexistence as the evidence for a link between those patterns and outcomes. For example, a high number of direct links between network members, indicated by a high network density, has been linked to better knowledge sharing and higher performance in project teams (see for example Chinowsky *et al*., 2008). This approach is limited in that it does not reveal the nature of this link and does not explain the relation between the two variables. It is argued that there is a need to explore the mechanisms through which network characteristics affect project outcomes (in this case, WHS outcomes), and vice versa. Put differently, a framework is required that establishes strong relations between dynamic social processes and project outcomes, such as WHS performance. Only with this level of understanding, solutions can be identified to effectively implement SiD. As highlighted by Lingard *et al*., (2012), in the collective, reflexive, and uncertain context of design, it is imperative that any study investigating the development [and implementation] of SiD processes should take into consideration the reflexive [and interactive] nature of design work and explain the way in which processes and/or tools 'fit' within design work.

Thirdly, decision making about WHS is a complex process which involves interaction between participants with different risk perceptions. Thus, understanding project participants' attributes (such as roles, behaviours and viewpoints) as they make decisions is an important step in explaining how and why social intra-project interactions take place and affect WHS related technical outcomes. Collecting qualitative data about the participants' attributes, the quality of their relations and the content of their interactions can help to understand how networks change and why certain outcomes emerge in projects. According to Loosemore (1998:315), "both quantitative and qualitative methods have a role to play in understanding the complexity of people's changing social roles, positions and behaviours within construction organisation". In a recent longitudinal study, Pirzadeh and Lingard (2017) combined SNA and in-depth interviews to account for the dynamism and temporal nature of the design process and its underpinning interactions. As the study revealed, each decision-making scenario involved specific knowledge sources and interactions. Consequently, the participants in making each decision and the pattern of interaction between them were specific to that scenario and changes were observed during the decision-making.

Fourthly, it is important to consider different levels of relationship and interactions in construction projects. At the macro level, construction projects are conceptualised as networks of firms administered by sets of contracts (Pryke, 2012). Winch (1989) refers to construction projects as 'temporary coalitions of firms' bound together by flows of information and material. These formal relationships are fairly stable, at least over each project stage, and would not change greatly unless the project goes through a major structural change. They provide the context for interactions between individuals or groups at lower organisational levels or may be regarded as the aggregation of lower level relationships. At micro level, construction projects can be viewed as networks of participants from different firms who engage in social interactions and perform project tasks. The uncertainty inherent in undertaking project activities makes it difficult to apply a centralized approach to decision-making and calls for decentralization of authority and strong reliance on localized decision-making (Dubois and Gadde, 2002). Thus, interactions at this level are often informal, and can be highly transient and ad hoc to rapidly suit and support local decision-making requirements. However, project participants also work in the context of their firms and consequently affect and get affected by the relationships that their firms are involved in. Therefore, the macro and micro levels of relationships may display important interdependencies, and relationships at each level might be best explained in conjunction with relationships at the other level. In fact, since organisations [including project temporary organisations] are multilevel systems, a network approach to study and explain organisations should also be multilevel in scope, considering how networks at one level influence network at higher or lower levels (Moliterno and Mahony, 2011).

CONCLUSIONS

Effective implementation of SiD in construction requires collaboration and effective interaction between design and construction decision-makers. Particularly, the project interaction networks need to support the integration of construction knowledge to the design process. However, design process is collective and complex. In addition, the socio-technical context of construction projects is dynamic and unpredictable. These characteristics create challenges for creating and maintaining effective interaction networks that underpin informed design decisions which are safe and constructible. It is proposed that project teams benefit from continuous mapping and understanding project communication patterns. This can particularly be helpful to implementation of SiD. Understanding interaction patterns can highlight opportunities for involving participants with construction knowledge in the decision process as well as encouraging free flowing information between participants to produce better decision outcomes. This, in turn, requires approaches that acknowledge the complex, dynamic and multilevel nature of the project interactions.

It is argued that there is a need for longitudinal studies that take a multilevel network approach and combine quantitative and qualitative data to capture and analyse interaction patterns prospectively as they happen in the dynamic context of construction projects. In line with this argument, a PhD study is currently underway. The aim of the study is to explore the way in which interactions between design and construction participants underpin collective decision-making and impacts upon construction WHS. To appreciate the complex context of construction projects, qualitative and quantitative data are integrated and a multilevel network approach is adopted. In addition, the dynamism in interaction pattern is captured by mapping communication patterns at each decision-point along the design decision-making process. The research outcomes are expected to contribute to more effective implementation of SiD in the construction industry as a proactive way of achieving better WHS outcomes.

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