KNOWLEDGE TRANSACTION BETWEEN OFFSITE AND ONSITE INTERFACES

Kingford Mkandawire[1], Shabnam Kabiri and John Connaughton

School of Built Environment, University of Reading, White Knights, Reading, Berkshire, RG6 6AH, UK

Interface discrepancies continue to cause buildability problems when incorporating offsite elements/products into onsite construction. One important challenge in this regard is related to effective knowledge exchange across structural and organisational boundaries to coordinate and manage the interface discrepancies. Distributed Situation Awareness (DSA), with its focus on the knowledge transactions between social and technical systems, allows the analysis of knowledge exchange in the offsite and onsite interfaces. A case study of roof-hanger buildability incident is presented. The data are collected in the one case project in the UK through direct observations on-site, semi-structured interviews, and documents and emails. Three main phases were identified in the incident: The transition, response to the discrepancies, and reactive measures. The analysis shows that there was a decrease in coordination and knowledge exchange in all three phases. It is concluded that viewing the knowledge transactions in the incident from a socio-technical perspective made it possible to determine who knows what at a given time. This ultimately makes it possible to show knowledge interdependence in the project system.

Keywords: Distributed Situation Awareness; exchange; interface discrepancies

INTRODUCTION

Offsite elements have been adopted by the construction industry in a recent drive to modernise its operations and increase its productivity (Goulding *et al.,* 2015). Operations that were traditionally conducted on-site are instead done at an offsite manufacturing factory, with the offsite products transported and installed by a different organisation. Having operations of the offsite products done in the factory and installed directly onsite has been argued to provide advantages in terms of speed, quality, waste management, and cost (McCarney *et al.,* 2022). However, interfacing the offsite products supplied or installed by different manufacturers and subcontractors onsite requires careful coordination to deal with a range of interface discrepancies that give rise to potential buildability problems (Pan *et al.,* 2023).

Interface discrepancies across various building elements are caused by factors emerging from the design, manufacturing, and construction processes (McCarney *et al.,* 2022). Not all the individuals involved in the interfaces are aware of what was designed and produced. This fact can create challenges in interfaces. Project participants may have different interpretations of functional requirements, work to various technical standards, or have different work practices (Talebi *et al.,* 2021). The

[1] kingford.mkandawire@reading.ac.uk

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separation of design, manufacturing, and installation creates different functions and roles (Fellows and Liu, 2012), which can turn into organisational barriers to effective knowledge exchange, particularly in offsite construction (OSC) (Liu *et al.,* 2022). Some scholars argue that this is exacerbated by the adversarial, and short-term relationships that prevail in construction settings. (Fellows and Liu, 2012, Mccarney *et al.,* 2022).

The current and future success of offsite and onsite construction incorporation relies on the social and technical interdependencies that facilitates knowledge exchange (Liu *et al.,* 2022). The right knowledge being distributed at the right time among project interfaces facilitate organisational processes (Bosch-Sijtsema and Henriksson, 2014; Liu *et al.,* 2022). This paper explores how distributed knowledge calls the essence of coordination between interfacing organisations about building elements in instances of interface discrepancies.

To study knowledge distribution and exchange in the interfaces, the research introduces the concept of *installation gap*. The *installation gap* describes the 'space' in a workflow between building elements (offsite and offsite building elements or offsite and in-situ building elements). In this process, the focus is on the activities with finish to start relationships meaning the installation or construction of the second building element can start after the first building element is installed or constructed. A sociotechnical systems approach was adopted to view humans as assets rather than the source of the interface discrepancies. The primary research question is to explore how knowledge is distributed within the construction system when there is an installation gap.

LITERATURE REVIEW

Many performance problems with OSC are attributed to poor interface management in the design, manufacturing, on-site installation, and technological immaturity (Pan *et al.,* 2023; McCarney *et al.,* 2022). An interface is defined as "a boundary where interdependence exists across that boundary and where responsibility for the interdependence changes across that boundary (Healy, 1997, p.68). Pavitt and Gibb (2003) while exploring interface issues in Building Façade demonstrated that interface management can enhance communication and coordination for managing the organisational, contractual, and physical interfaces. Ahn *et al.,* (2017) found that current interface management practices are effective in addressing complexity factors related to scope, communication, and multiple project stakeholders, but they are not effective in dealing with project complexity originating from engineered items. In this specific research, this result was surprising given the availability of interface manager and interface coordinator roles within the case study of the research. This conclusion challenges the clarity of such roles, their responsibilities and, essentially, effective interface management practices. Further research can shed light on how the participants involved in the interfaces interacted and/or coordinated around the interface matters.

Interdependence, specifically, task interdependence, which is defined as the extent to which project members must interact and depend on each other for the work to be accomplished (Bygballe *et al.,* 2016), has been recognised as the leading element in interface management. Primarily, task interdependence is managed through coordinating, which is explicitly done through planning and communication or implicitly via anticipation of others' needs (Bygballe *et al.,* 2016). These studies describe how both planned and emergent structures can help with the coordination of

the efforts of project participants who work interdependently on tasks (e.g., installation tasks). However, the focus on coordination and interaction among people as they work interdependently has focused less on the technical interdependence of the interfacing building elements which are the focal point of the task. As a result, interface discrepancies have been considered to emanate from people only, leaving out the interaction of the people and technical elements.

As more offsite products are being introduced into construction projects, interdependences among them or with the in-situ building elements spring up. Such interdependence is referred to as building elements interdependence in here. More specifically, building elements interdependence is defined as the interfacing building elements that are design, structural, and programmatically interrelated to the extent that one cannot be installed if the other has not been installed.

As offsite products continue to rise in the construction industry, understanding building elements interdependence may be as important as understanding task interdependence to address joints, connections, and interface issues (Pan *et al.,* 2023; McCarney *et al.,* 2022). Understanding the sociotechnical system in understanding building element interdependence will help to unpack how coordination happens and how coordination failures could be avoided. To do so, this paper adopts a sociotechnical system approach to examine knowledge exchanges that activate coordinating needs when incorporating offsite products into onsite construction.

Distributed Situation Awareness (DSA) Theory as a Theoretical Background

Distributed Situation Awareness (DSA) theory focuses on how information and knowledge are distributed across sociotechnical systems. The focus is on the awareness that is distributed across human agents (e.g., project participants) and nonhuman agents (e.g., artifacts such as tools, documents, and displays) of a system. Central to DSA is the notion of "transactions" between agents as the mechanism through which a system retains awareness while performing a task (Stanton *et al.,* 2006). A transaction in this context refers to an exchange of situation awareness between agents. It encompasses more than just the conveyance of information (Salmon *et al.,* 2009). In a transaction, agents communicate or coordinate with one another, exchange information, act on it once it has been combined with other information, and then transfer that information to other agents (Salmon *et al.,* 2009). Each agent has a unique interpretation of that information. For instance, information regarding a particular building element detail may rightly be used and interpreted differently by the subcontractor or trade as it is combined with other information to enable each to carry out their specific task. Both are utilising the same information for their respective purposes, including it in their respective schemas, and coming to their interpretations (Stanton *et al.,* 2006). Without any necessity for parity of meaning or purpose, elements of one agent's situation awareness can interact with those of another.

Reflecting on the aim of the study, using the lens of DSA and considering the incorporation of offsite products into onsite construction as a sociotechnical system, this research attempts to answer what transactions in awareness could result in better coordination based on the specific case of this study.

METHOD

Using the lens of DSA theory, the focus of the study is on the knowledge transactions between the project's sociotechnical system to manage interface discrepancies. The

aim is to understand how knowledge related to interface discrepancies is transacted across the agents (Humans-Designers, Manufacturers, Main Contractors, Subcontractors, and nonhumans-drawings (2D and 3D), etc). Studying the knowledge transactions during the actual installation/construction tasks as a phenomenon involves direct contact and close interaction between the researcher and the project interfaces. The research adopts a longitudinal case study approach to investigate and describe the events as they unfold in the real-world context (Creswell, 2014). The data are collected for a period of 5 months in one case project in the UK through direct (nonparticipant) observation on-site, 6 semi-structured interviews, and document and email reviews. The project included the installation of Structural Insulated Panels (SIPs) for wall and roof panels and the timber cladding. To maintain focus on the interfacing issues happening during the installation tasks, the research targeted onsite participants from the Main Contractor, Manufacturer, and Cladding Subcontractor. Interviews were conducted face-to-face averaging a duration between 30mins and 45mins. By using active interviewing (Cicmil *et al.,* 2006), the participants were encouraged to share their reflections and accounts of the installation gaps during the installation tasks. In this case study project, there was an installation gap related to roof-hangers.

THE PROJECT AND ROOF-HANGER BUILDABILITY INCIDENT

The construction project is in West London, England, and is a new single-story school for children with special needs and disabilities. The project is a design and build contract, with a construction cost of £11.4million. The ground floor area is 2500m². Australian Construction Exchange (Aconex) was used for construction project information and process management (managing processes, documents, drawings, building information models, communications, workflows, and audit trails. During the installation works, there was a roof-hanger buildability incident because of the discrepancy between the manufacturer and the cladding subcontractor. The cladding subcontractor observed that the roof overhand constructed by the manufacturer was out of tolerance by 100mm as it was supposed to be 300mm from the wall, but it was 400mm. The tolerance issue had a negative impact on the cladding brackets as they could not be structurally approved to support the timber cladding. Hence, a 91m length of the roof-hanger had to be cut short to align with the timber cladding details.

ANALYSIS

For the analysis of this *installation gap*, using the DSA lens, technical agents including construction drawings (both 2D and 3D), sketches/representations, and information platforms were considered. DSA analyses include defining a system's awareness during several task phases and focusing on transactions between 'agents' (Stanton *et al.,* 2006). To do so, the roof-hanger buildability incident is grouped into three main phases: 1) the 'transition'- after the subcontractor completes work, 2) the response to the discrepancies, and 3) the reactive measures to the buildability incident.

To identify keywords that represented different informational pieces in all three phases of the incident, a content analysis was done. The DSA framework, which sought to distinguish between function words and content words, guided this action (Stanton *et al.,* 2006). To highlight the contextual pieces of information distributed in the system, a prepositional network is constructed from the information elements extracted in the content analysis of the transcribed interviews. These were compared with the observation notes and the email exchanges to increase the credibility and reliability of the data (Creswell 2014) .

A propositional network is described by Salmon *et al.,* (2009) as "a network showing the information underlying a system's awareness and the links between the different bits of information"(Salmon *et al.,* 2009, p. 60). Through this, a clear picture of the systems' awareness is shown, and it is possible to track the effects of transactions (or lack thereof) over time. The propositional network for the roof-hanger and cladding incident is presented in Figure 1.

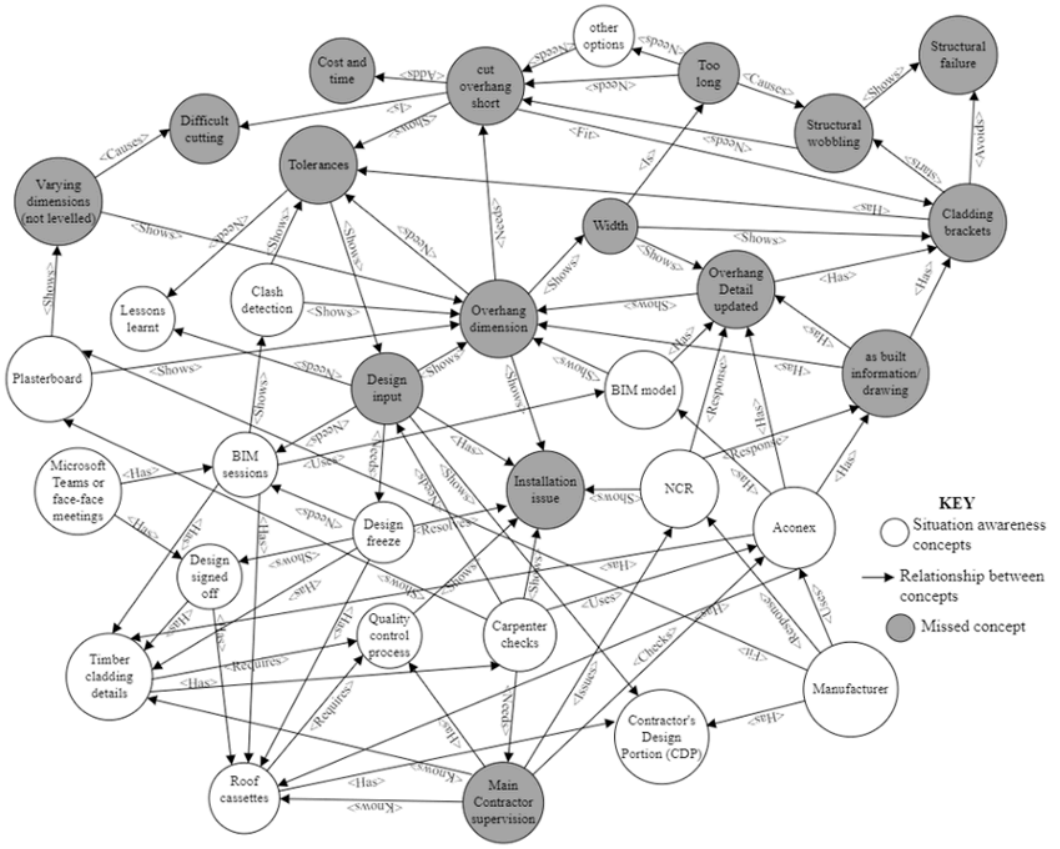

Figure 1: Propositional network for the whole roof-hanger incident

The analysis highlights which aspects of the communication between human and non-human agents underpinned the incident-that is, which information pieces were available or were not available to the key agents at the right time. Verbatim comments are also included in the analysis and findings to indicate the reflections, perspectives, and experiences of the human agents involved.

To begin with, an important concept within the network is overhang dimension which shows that the width was too long beyond the designed width to accommodate the cladding brackets. This transaction in awareness led to the discovery of the installation issue which triggered the need to cut short the overhang, a length of 91m. The Main Contractor and Manufacturer during the installation of the roof-hanger had (cladding brackets, overhand dimension, width, Aconex) information nodes. But they had no transaction awareness of the tolerances and the dimension width to enable the cladding brackets to fit and hold the timber cladding. The Main Contractor was not aware of what tolerances or width the Manufacturer was installing. Further, the Main Contractor was not aware of the Manufacturer's intentions around controlling the tolerances and width of the overhang. There was a shortfall of transaction awareness between the Main Contractor and the Manufacturer.

In addition, the finding puts into question the Main Contractor supervision within the network, which suggests an overreliance on the subcontractors to finish the task under minimal supervision as they are assumed to have the full knowledge of the task. This could have a negative implication on transaction awareness of what is being built and what was designed. It is observed that during the installation works, the Main Contractor was not aware that the roof overhang was not installed as designed. This is acknowledged by the Quantity Surveyor:

> What we should have done is measuring things ourselves and visiting the factory, which we should not be doing because they are deemed as a competent subcontractor...they are experts. This is a case of their ends - internal processing like undertaking checks and all that kind of stuff, making sure everything is according to the design. (Quantity Surveyor, Main Contractor)

The Main Contractor and Manufacture did not refer to or discuss the overhang dimension, which brings into question whether both were aware that the cladding brackets required a specific width to attain structural integrity. The Manufacturer acknowledges that the manufacturing and installation of the roof cassettes were within their tolerances (+/-25mm). When the Cladding Subcontractor was setting up the task for cladding installation and did the dimension checks, it was discovered that the plasterboards had dimension variations (between 40mm and 50mm). This relates to a lack of awareness regarding the purposes of the cladding brackets. If the Manufacturer and the Main Contractor did have knowledge of the purpose of cladding brackets, they could have discussed that dimension variations will lead to difficulties in fitting the cladding brackets or cause structural failure due to wobbling of the cladding brackets.

The concepts relating to design signed off, overhang detail updated, and as-built information/drawing shows shortfalls in human-to-human and non-human-to-human transactions in awareness. The Manufacturer is of the view that the installation task of the roof-hanger was done based on the design that the Main Contractor signed off. However, the Main Contractor insists that the installation task was not according to the design. Yet, the Main Contractor and Manufacturer access the same information sharing platform - Aconex. It is unclear why the Manufacturer and Main Contractor could have different information. The interview quotes the Senior Site Operation Manager from the Manufacturer suspecting that the Main Contractor changed drawing details in Aconex.

> The drawings we submitted were accepted and signed off by the Main Contractor, but at a later date they said the drawing needs to be something else. You will get (nearly) to the end of the job, and they will change. The model was different from how we interpreted it in the first place. They change the model and change over the surveyor who has a new pair of eyes and can claim that they do not know what went on and use that as a reason not to pay the money. The lesson is, do not work for this Main Contractor again. (Senior Site Operation Manager, Manufacturer)

If the model/drawing information was updated in Aconex, does it mean that Aconex did not generate an alert or notification to the relevant parties about this? Or does it not have an unalterable audit trail to capture and track any sudden information updates? Any cloud-sharing platform should have a prerequisite audit trail setting. This shortfall in transaction awareness between non-human-to-human could fuel uncountability and disputes in construction projects. If Aconex had generated an alert and audit trail, then any information updated could have been noticed by the interfacing parties. Moreover, it could be that the Manufacturer is not fully familiar with Aconex usage, or the Main Contractor did not check the settings. This questions

the design of Aconex training, and whether more can be done to address the challenge that the Manufacturer or Main contractor faced. Furthermore, there was no transaction awareness between the Main Contractor and the Manufacturer on the design drawing and as-built drawing. The Project Manager outlines this:

> One of the responses we have got back in the non-conformance report (NCR) is that it is a changed detail. They cannot change the detail without us approving it. If they changed the detail and we approved it, then there is a bit of an argument and a bit of a slap on the back of the hand or for whoever signed that off, because that is not what we wanted and we need to learn from that, but the Manufacturer cannot update a detail in Aconex without us commenting against it. This was my argument back to them to say well, it still stands in your court because you might update the detail, but you did not send it to us. (Project Manager, Main contractor)

A final interesting concept is that of 'other options', which questions the effectiveness of the design and onsite meetings conducted online (through Microsoft Teams) and face-to-face when it comes to resolving interface issues at an early stage. The concept of 'other options' confirms the interaction and coordination aspect of making sure that the required width to fit the cladding brackets was achieved. The meetings initiating the reactive measures to resolve the incidents were mostly done face-to-face onsite. Importantly, it was only after the prevalence of the overhang incident that much emphasis and coordination was put on the fitting of the interfacing building elements. The finding could mean that during the design and onsite meetings, high coordination was more tied to task dependency whilst there were low levels of coordination between building element interdependence. Hence, when the knowledge of the discrepancies was activated between the interfacing parties, higher levels of coordination on the interfacing building elements were observed. The findings also suggest that online meetings (Microsoft Teams or Zoom) may be suitable for discussing task interdependence but not building elements interdependence. Senior Site Operation Manager reflected on online meetings:

> I feel like people are not committed in Microsoft Teams meetings. We are better off face-to-face. There are fewer sketches in Teams to emphasize your point and there is less motivation, and it is a bit like people are busy using their mobile phones.... there is a bit of frustration. Teams' meetings work well in some regards, and maybe other organizations prefer teams other than face-to-face meetings. (Senior Site Operation Manager, Manufacturer)

DISCUSSION

The analysis presented aids the understanding of DSA in examining the interface discrepancies by identifying a subset of knowledge transactional-related failures occurring in the construction sociotechnical system. The network constructed represents the pieces of information (concepts) that the interfacing organisations could have used to help understand the situation, respond appropriately, and prevent the incident. The pieces of information reflect knowledge transactions in the *installation gap* (between the overhang and timber cladding). In line with sociotechnical thinking, the research focuses on the interaction between agents rather than the agents themselves. For instance, the focus is not on the Manufacturer not being aware of something, but rather it is on the interaction between the agents that did not allow the appropriate knowledge transaction to be distributed as it should have been. This means that the sociotechnical system comprising the Main Contractor, Manufacturer, Cladding Subcontractor, Aconex, BIM models, and construction project systems did not facilitate appropriate knowledge transactions to avoid the incident.

The study shows that three classes of transaction awareness failure were uncovered namely, absent transactions, inappropriate transactions, and misunderstood transactions (Salmon *et al.,* 2016). These failed transactions have been described as the root of incidents occurring in sociotechnical systems (Salmon *et al.,* 2016). Absent transactions are instances in which a transaction in awareness was required but was not initiated. This includes scenarios in which the exchange should have occurred, but it did not due to a failure of some kind (e.g., inadequate details, inadequate quality control processes). Inappropriate transactions occur when a transaction in awareness is initiated but the transaction content is incorrect. This includes scenarios in which the human or non-human agent initiating the transaction (e.g., Aconex, drawings) provided incorrect information or the awareness being exchanged is incorrect. Misunderstood transactions occur when the receiver misinterprets the information or image being transferred.

Overall, the findings show the project system had low levels of coordination tied to building elements interdependence before the incident. This resulted in failing to capture the knowledge (i.e., tolerances, width) for coordinating both the Manufacturer and Cladding Subcontractor building elements. The findings are in line with Ahn *et al.,* (2017) that interface management practices are not effective in dealing with project complexity originating from engineered items/components. This could be that there is low knowledge exchange or unfamiliarity with the interfacing building elements leading to the complexities. When planning, designing, manufacturing, and installing building elements interfaces, the construction project system should embrace knowledge interdependence to address the interface discrepancies.

Knowledge interdependence between the agents describes the disparities between agents' knowledge and expertise as well as the potential outcomes of agents having compatible knowledge (Raveendran *et al.,* 2020). Previous research in modular construction highlights interface problems and recommends that improvements in the design, and more interaction and knowledge exchange between the design team, manufacturer, and different trades could avoid interface problems (Pan *et al.,* 2023). This was verified in the findings from the case study, which observed that interface discrepancies were addressed during the incident. This was because of low knowledge interdependence levels between interfacing parties at an early stage.

Lastly, the study highlights that online meetings could be best suited for coordinating task interdependence but not for coordinating building elements interdependence. Face-to-face meetings are effective for capturing patterns of knowledge transactions through sketches and other representations which were discussed as difficult to show during online meetings (Microsoft Teams/Zoom). The knowledge exchange during face-face meetings aids a higher level of common understanding to ‘fit together’ the interfacing building elements. Common understanding is high when agents in an interdependent task transact knowledge of the task that is to be done, how it should be done, and its aims and objectives (Bygballe *et al.,* 2016). Thus, information management systems (e.g., Aconex), drawings, BIM models, or other details drawn by the organisation to facility interface meetings should be designed to embody common understanding. This is because knowledge exchange is facilitated by different social and technical processes (Barley *et al.,* 2018).

CONCLUSION

The research presented in this paper viewed knowledge transactions in the buildability incident from a sociotechnical perspective. This made it possible to determine who

knows what at a given time in the *installation gap*. The study shows three classes of transaction failures that contributed to the incident, absent transactions, inappropriate transactions, and misunderstood transactions. These transaction failures contributed to low levels of knowledge interdependence for coordinating the interface discrepancies.

The implication of this paper is on two themes, with an emphasis on 'Constructing the Future'. First, to avoid costly rework in OSC, the project system design should be flexible in balancing levels of coordination related to task interdependence and building elements interdependence to understand interface issues, joints, and connections. Secondly, by understanding why and how to interface discrepancies or buildability incidents occurred, it is possible to suggest ways of designing and developing systems (e.g., to increase salience including online meetings) and training procedures (e.g., Aconex usage) to facilitate higher levels of knowledge interdependence and coordination between interfaces.

One limitation of this study is that factors and behaviours influencing high or low coordination practices related to building elements interdependence were not considered. Future research should continue to delve into the role of transactional situation awareness to find out what factors influence the development of low versus high-coordinating practices and mechanisms for managing building elements interdependence in knowledge work. Such a study is crucial to advance the OSC field and bridge the gap between the concepts and approaches presented in the literature and what project participants experience (Cicmil *et al.,* 2006).

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