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THE DESIGN-CONSTRUCTION COMMUNICATION LOOP: A CONCEPTUAL MODEL FOR COMMUNICATION ERROR ANALYSIS

Frode Drevland[1] and Fredrik Svalestuen[2]

ABSTRACT

The paper introduces a novel conceptual model designed to analyse and mitigate communication errors within the design-construction interface of construction projects. Recognising the complexity of communication in construction projects, the model integrates three foundational theories: Koskela's Transformation-Flow-Value (TFV) theory, Gero's Function-Behaviour-Structure (FBS) model, and Shannon and Weaver's communication theory. This interdisciplinary approach allows for a comprehensive examination of the information flow between the design and construction processes, highlighting potential transformation and flow errors at each stage. The model categorises errors into transformation errors, intrinsic to specific processes, and flow errors, which result from upstream issues, providing a framework for targeted quality control measures and root cause analysis. However, the model acknowledges its limitation in addressing the temporal aspects of communication, a critical factor in construction project management. The paper argues that, despite this limitation, the model offers significant insights for academics and practitioners by providing a structured method to identify, analyse, and address communication errors, thereby enhancing the efficiency and effectiveness of information exchange in construction projects.

KEYWORDS

Lean construction, theory, construction communication, information flow

INTRODUCTION

Studies from around the world point to poor and lacking communication as one of the main culprits for various issues in construction projects – including being a leading cause of delay (Doloi et al., 2012), rework (Yap & Tan, 2021), dispute (Gamil & Abd Rahman, 2022), poor productivity (Al-Rubaye & Mahjoob, 2020), as well as one of the main barriers to the implementation of sustainable construction (Susanti et al., 2019). Other studies point to the unique characteristics of construction projects - such as their complexity (Cakir et al., 2022) and having a multicultural workforce (Loosemore & Lee, 2002) – being the cause of significant communication issues.

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While there is no lack of literature pointing to communication as a substantial issue for the construction industry, there is generally a dearth of research on communication in construction projects (Emmitt et al., 2009). In the literature review leading up to the paper, we found few papers reporting in-depth empirical studies nor trying to develop any further theoretical understanding of communication issues in construction projects.

In the lean construction community, authors often mention communication. However, little of the published research is primarily concerned with communication issues. Of all the papers published through the Lean Construction Journal and the proceedings of the annual IGLC conferences, nearly eight per cent include the word "communication" in the abstract. However, less than half a per cent includes the word in the title.

Furthermore, lean construction-related papers about communication tend to focus on the practical use of concrete methods, tools or technologies for improving communication – such as Design Thinking (Spitler & Talbot, 2017), Last Planner System (Lagos et al., 2022), Stakeholder Management (Sosa & Torre, 2021), Design Metrics (Mulholland et al., 2022), and tablets (Aasrum et al., 2016).

Tools and technologies can undoubtedly alleviate communication issues. However, there are areas where they have fallen short. According to Dainty et al. (2007), the flow of information between the design and construction processes is a particular problem in the building industry. Even with newer collaborative contracts and faster communication with ICT- tools like BIM, the industry fails to rectify the problem. We would argue that this failure can be attributed to a failure to understand the communication taking place properly. Before developing tools and technologies to support communication better, we must clearly understand what is being communicated and the very nature of the communication process.

The advent of lean construction brought production science back into project management, and construction projects are now commonly referred to as production systems (Koskela & Ballard, 2003). We would argue that the design and construction processes of construction projects can be considered distinct but tightly coupled production systems. One produces an immaterial product – the design – and the other produces the physical manifestation – the built facility. Furthermore, we would argue that understanding the communication between the design and construction processes can require understanding the coupling between them from a production-theoretical point of view.

While several frameworks have been developed to support communication processes in the construction industry (Zerjav & Ceric, 2009), none consider such aspects. Common for them all is that they "are based on identifying a series of project phases in terms of communication's form and content that is taking place during a particular phase". We would argue that such models work well for prescriptive purposes – to define what information should be delivered, when, and how. However, they do little to help us understand or analyse communication errors in construction projects.

This paper introduces a conceptual model designed to serve as an analytical framework for identifying and addressing communication errors within the design-construction production system interface. This endeavour synthesises insights from three seminal theories across production, design, and communication: Koskela's Transformation-Flow-Value theory, Gero's Function-Behaviour-Structure framework, and the Shannon-Weaver communication model. Integrating these foundational models lays the groundwork for a comprehensive understanding of the flow of information and immaterial products at the critical juncture between design and construction processes.

The paper begins by describing the three foundational models. Subsequently, we articulate the development of our integrated model, the Design-Construction Communication Loop (DCCL), emphasising its capacity to elucidate the complexities and potential pitfalls in communication between the design and construction process. We then introduce a typology based on the DCCL, which categorises common communication errors at the design-construction interface. In the concluding sections, we explore the practical implications of the DCCL, highlighting its potential to improve information flow and project efficiency in construction. While we recognise the model's contributions, we also address its limitations, such as not accounting for time, paving the way for future research to refine and expand the DCCL's applicability.

FOUNDATIONAL MODELS

This section introduces the three fundamental communication, production, and design models. These form the basis of the Design-Construction Communication Loop (DCCL) model, detailed in the next section. We have chosen each model for its significant impact in its respective field, and together, they provide a solid framework for understanding communication between the design and production processes in construction projects. This section aims to succinctly outline the key features of these models, setting the groundwork for our integrated approach in the subsequent part of the paper.

PRODUCTION – THE TFV THEORY

Koskela's (2000) Transformation-Flow-Value (TFV) theory has been instrumental in shaping our understanding of production in lean construction, making it a natural choice for our model's foundation.

Koskela identified three distinct conceptualisations or views of production: transformation, flow, and value. He integrated these into the TFV theory, offering a comprehensive framework for examining production systems. The traditional view, which he termed "transformation", sees production as converting inputs into outputs, breaking down larger processes into smaller, optimisable parts. However, this view often overlooks non-value-adding activities like transportation and waiting, which Koskela addresses in the "flow" aspect. This second concept focuses on streamlining the movement of materials and resources, identifying and minimising waste.

The third concept, "value", challenges the potential sub-optimisation of focusing solely on transformation. It emphasises understanding and fulfilling customer needs, both internal and external, ensuring that each step in the production process contributes to the end goal.

Koskela extends the TFV theory to all production systems, including design work. He argues that design activities are transformations—designers turn customer needs into solutions. The flow in a design process is typically the flow of information between each designer, and the value aspect is a means to an end discussion between designer and customer.

COMMUNICATION – THE SHANNON–WEAVER MODEL

Communication theory is a diverse field encompassing various perspectives and models. Craig (1999) notes that while there are numerous theories, they generally align with one of seven traditions, each offering a different lens through which to view communication:

1. Rhetorical – Communication as a practical art of discourse
2. Semiotic – Communication as intersubjective mediation by signs
3. Phenomenological – Communication as the experience of otherness
4. Cybernetic – Communication as information Processing
5. Sociopsychological – Communication as expression, interaction, and influence
6. Sociocultural – Communication as the (re)production of social order
7. Critical – Communication as as discursive reflection

Of these seven conceptualisations, modern models for communication theory tend to belong to the cybernetic tradition (Craig, 1999). In the cybernetic tradition, communication is understood as the exchange of information and knowledge among individuals. – essential in complex building projects. While authors have proposed various refinements and variants, the existing models all track back to Shannon & Weaver's (1949) seminal work, *The Mathematical Theory of Communication*. Figure 1 shows their model.

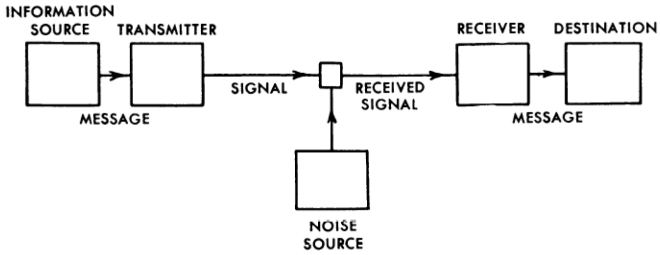

Figure 1: Schematic diagram of a general communication system (Shannon et al., 1964)

Shannon & Weaver's model, initially developed at Bell Labs, was primarily focused on the accurate transmission of signals, not necessarily as a comprehensive communication theory (Ritchie, 1986). However, it inadvertently became foundational in the field of communication, providing insights into both engineering and human interaction aspects. Despite its widespread application, the model has been critiqued for its limited capacity to fully represent human communication complexities (Heath & Bryant, 2013)

Addressing these critiques, various adaptations have been proposed over the years. This paper particularly references a variant by Kaufmann and Kaufmann (2009), which introduces significant modifications to the original model. The primary distinctions in this variant include a feedback loop and the recognition that noise can impact any part of the communication process, not solely the transmission channel.

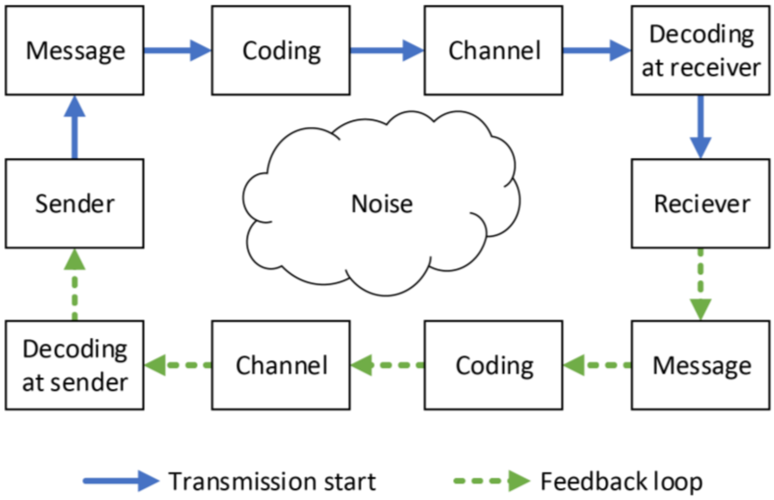

Figure 2 Components of the communication process (based on Kaufmann & Kaufmann, 2009)

Shannon and Weaver's original model centred on noise as information loss during transmission. Subsequent interpretations by other authors, such as Coupland, Giles, and Wiemann (1991); Fiske (1990); and O'Sullivan (1994), have broadened this concept to include losses due to faulty encoding or decoding. While different authors acknowledge the difference between noise in the channel and other noise (Brogan, 1974; Coupland et al., 1991; O'Sullivan, 1994; Pearson et al., 2005), there are no standard naming conventions. Since encoding and decoding are internal processes with the sender and receiver, this paper refers to noise affecting encoding and decoding as *internal noise* and noise affecting the transmission through a channel as *channel noise*.

Channel noise tends to be physical (O'Sullivan 1994). Common examples include background traffic noise during a conversation or sunlight obscuring a projection screen. Such noise is usually overt and can be relatively easily addressed. For instance, if a phone call is marred by poor reception, the receiver might suggest hanging up and calling back or switch to a different communication medium. Therefore, channel noise often leads to delays rather than direct errors, provided the communication process incorporates feedback mechanisms.

In contrast, internal noise encompasses a variety of more subtle interferences. One key type is semantic noise, defined by O'Sullivan (1994) as disruptions caused by differences in meaning. Differences in meaning can arise from language issues, such as inconsistent or ambiguous wording, or socio-cultural disparities between the sender and receiver, with professional jargon as a prime example. Another significant category is psychological noise, which pertains to interference from personal biases and assumptions (Rothwell, 2004). This noise stems from an individual's preconceptions and can significantly distort the intended message. Understanding and addressing both channel and internal noise is crucial for effective communication in complex environments like construction projects.

DESIGN – THE FBS MODEL

Design research, emerging formally in the 1960s and 1970s, initially grappled with significant challenges. According to Gero and Kannengiesser (2014), early efforts in this field were hindered by the lack of established terminologies and universally accepted concepts. Additionally, the prevailing perception among researchers was that design was a unique, irregular process lacking consistent patterns or principles.

This perspective shifted as subsequent studies delved deeper, focusing not just on the superficial aspects of design but on uncovering its inherent regularities. Researchers started recognising patterns and consistencies within the design process, moving towards a more structured and theoretical understanding of design as a discipline. This evolution marked a critical transition in design research, laying the groundwork for developing more refined and comprehensive design theories and models.

One of the foremost examples of this approach is the Function-Behaviour-Structure (FBS) model, conceived by Gero (1990). The model represents a significant leap in conceptualising the design process, offering a framework that deciphers the ontology of design across various applications. The FBS model has evolved considerably since its initial introduction. This paper defers to the version of Gero and Kannengiesser (2014).

The Function-Behaviour-Structure (FBS) model, as depicted in Figure 3 and elaborated by Gero and Kannengiesser (2014), provides a systematic approach to design. It begins with identifying the purpose or requirements (R) of an artefact, for example, a building. Designers then determine the functions (F) the artefact needs to fulfil these requirements. The design process's ultimate goal is to create a comprehensive design description (D) that encapsulates these functions.

However, the FBS model posits that a direct transformation from function to description is not feasible in a design system. Before developing a description, there must be a defined structure (S) – a detailed arrangement of the artefact's components and their interrelationships. For example, in architectural design, this structure includes elements like doors, windows, walls, and their spatial and functional connections.

A direct transformation from function to structure is rare and, according to Gero and Kannengiesser (2014), does not constitute design in the traditional sense; it is akin to selecting a ready-made solution from a catalogue. Instead, the design process involves deriving expected behaviours (Be) from the set of functions. These behaviours provide a framework for how the artefact should operate to fulfil its functions.

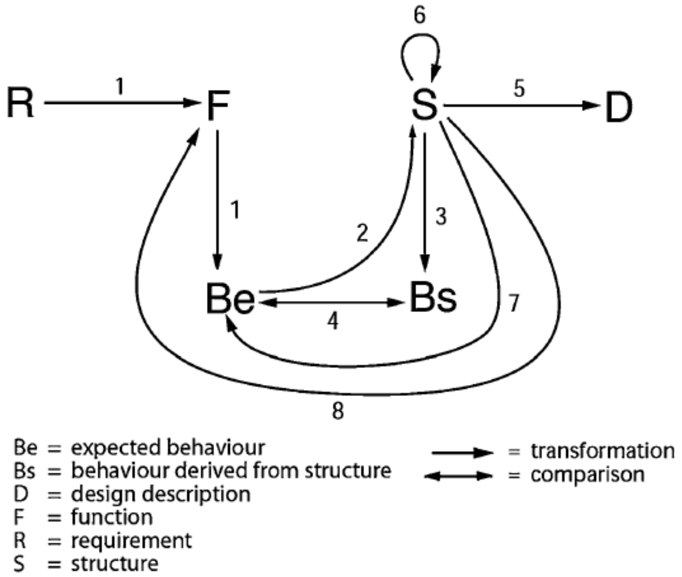

Figure 3: Gero’s FBS-model for design (based on Gero and Kannengiesser 2014)

Designers then work on synthesising a structure that aligns with these expected behaviours. Once a structure is proposed, its likely behaviour (Bs) is analysed. If this actual behaviour aligns with the expected one, the design is considered successful, leading to the final design description (D). If not, the process involves reformulation, which may include iterating on the structure or revisiting the expected behaviours and functions.

The FBS model is outlined through eight key transformation processes:

- Formulation (R to F, and F to Be)
- Synthesis (Be to S)
- Analysis (S to Bs)
- Evaluation (Be compared with Bs)
- Documentation (S to D)
- Reformulation Type 1 (S to a revised S)
- Reformulation Type 2 (S to a revised Be)
- Reformulation Type 3 (S to a revised F, via Be).

THE DESIGN-CONSTRUCTION COMMUNICATION LOOP

We will start explaining the developed DCCL model by considering the relationship between design and construction using Koskela’s TFV theory. The DCCL model considers both design and construction as transformation processes. The design process transforms customer requirements – including end-users needs and specifications from the construction process – into an intangible product, the building design. The construction process then converts this design into a tangible product, the physical building.

Key to this transition is the concept of flow, particularly in the movement of the design to construction. Unlike physical products, the design, an intangible entity, is transmitted not through physical means but via communication. Communication is the vital link between the design and construction stages, akin to a conveyor belt in a manufacturing setting.

The third aspect of the TFV theory is value. It might seem evident that the value produced by the design process is embodied in and equal to the drawings and descriptions the design process produces. However, we propose that these elements are better understood as communication artefacts. Design is about creating knowledge; thus, the actual product and value created lies with Gero's structure (S) of the FBS model. This idea implies that while designers may conceive an effective solution, translating or encoding this solution into drawings and descriptions is critical. This transition from Structure to Description in Gero's model is akin to encoding in communication theory.

This understanding leads to the DCCL model depicted in Figure 4, where various flow shapes represent transformations, actions, documents, and products. The model encapsulates the journey of a customer requirement being transformed by the design process into a solution, which the designer process encodes into a communicable form. The construction process decodes this information and transforms it into a physical product based on its interpretation of the communicated design. Importantly, this model emphasises two-way communication: the construction process also communicates back to the design team, potentially requesting new solutions or seeking clarifications, thus completing the design-construction communication loop.

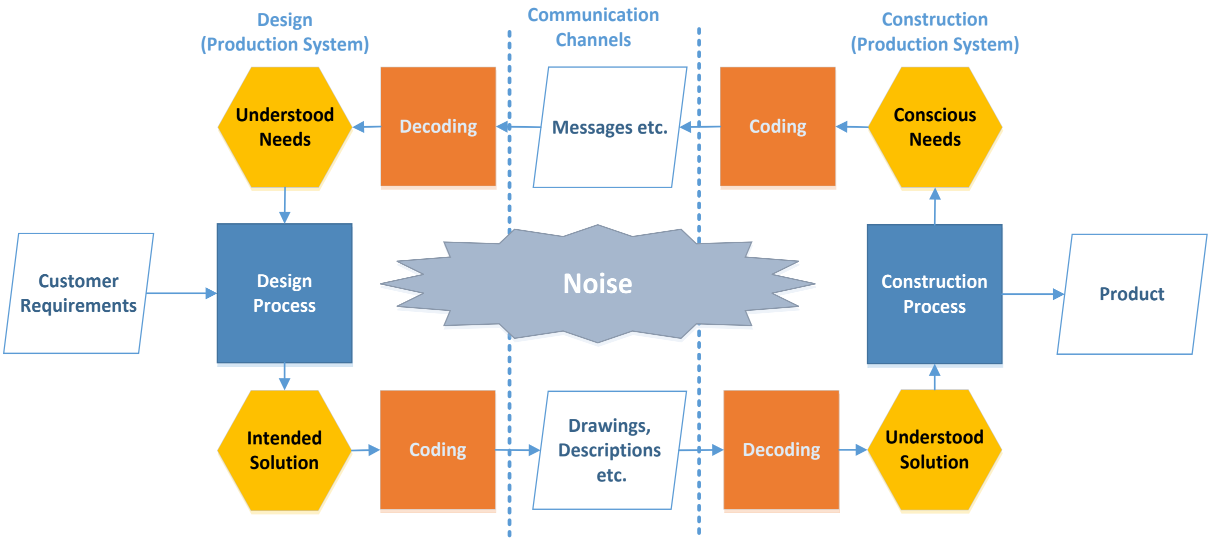

Figure 4: The DCCL model

The DCCL model has three main interconnected parts: the design production system, the construction production system, and the communication channels linking them. The model begins with the **Customer Requirements,** the needs and specifications driving the entire process. These requirements are akin to the Requirements (R) in Gero's FBS model and form the basis for the subsequent **Design Process**. It is important to note that defining these needs typically occurs in a pre-design phase, which is outside the scope of the DCCL model.

The Design Process transforms the Customer Requirements into an **Intended Solution**. This process mirrors the FBS model, where Requirements (R) are converted into a Structure (S). In other words, this step in the DCCL models phase encapsulates several steps of the FBS model, representing a high-level abstraction.

The Intended Solution, the output of the design process, corresponds to the Structure (S) in the FBS model. The next step, **Coding**, involves translating this solution into communicable forms like drawings, descriptions, or models, effectively serving as the transmitter in Shannon & Weaver's terms.

These outputs, **Drawings, Descriptions, etc.,** represent the media travelling through the communication channel. The channel varies, from face-to-face meetings to digital platforms like email or document servers.

The **Decoding** step is where the construction team interprets these transmitted designs. This process involves transforming the explicit design descriptions into an implicit understanding of the solution, laying the groundwork for the construction process.

The **Understood Solution** is the outcome of the decoding step, forming the basis for the **Construction Process** – the physical transformation of materials into the built facility, based on this interpreted design.

Conscious needs arise within the construction process, reflecting the team’s need for additional information, clarifications, or modifications from the design team. These needs may range from requests for more detailed descriptions to identifying and addressing design errors.

Finally, **Messages etc.** represent the media used to convey these conscious needs from the construction team back to the design team, completing the communication loop and ensuring a dynamic, responsive process.

To illustrate the model with a practical example, consider this scenario: The project owner has a specific requirement for an elevator that can lift 10 people or 1200kg up three floors from the basement. This requirement is conveyed to the design team, which then transforms it into a detailed intended solution. The designers encapsulate their solution in a description using the most appropriate medium, such as a Building Information Modeling (BIM) model. This BIM model is then transmitted via a suitable communication channel, such as email or a shared digital server.

Upon receiving the BIM model, the construction team accesses and interprets the encoded data to understand the design intent. If the construction team finds the information sufficient and clear, they proceed with building the elevator. However, if there are perceived issues, such as missing details or impracticalities in the design, they will initiate a feedback loop. They articulate their concerns in a message, which is then sent back to the designers through a communication channel like email. Upon receipt, the designers decode the feedback and make necessary adjustments to either the design itself or its description, ensuring it aligns with the construction team’s needs and clarifications.

This sequence of interactions highlights multiple potential points of failure that could lead the final product to deviate from the project owner's initial requirements. The following section will introduce a categorization scheme designed to help identify and address these potential discrepancies.

CATEGORISATION OF COMMUNICATION ERRORS

In the context of the DCCL, we created a typology for categorising communication errors between the design and construction processes, as detailed in Table 1. This categorisation framework identifies the different outputs from the model’s stages and associates two primary types of errors with each output: transformation errors and input errors. This division draws from Hopp and Spearman (2011), who differentiate between process and flow variability.

Transformation errors, in our context, are those that originate entirely within a specific transformation process. They are intrinsic to the process in which they occur. For example, a flaw in the construction phase, such as incorrect implementation of the design, would be categorised as a transformation error

Input errors, on the other hand, are errors that are not inherent to the process itself but are consequences of preceding issues, i.e. somewhere in the preceedcing flow of transformations. For instance, a flaw in the final product might stem from a number of different upstream issues, such as a fundamental flaw in the initial design concept, or errors in how the design was communicated (encoded) in the design documents. Similarly, issues might arise during the construction phase due to misinterpretation (decoding) of the design documents.

Table 1 Typology of communication errors in the DCCL model

	Transformation	Input
Design process	Errors in transforming customer requirements and construction process needs into a viable design solution, such as design flaws or oversight of critical requirements; failure to recognise the need for additional information or clarification.	A well-executed design process, but based on misinterpretation, ambiguity, or omission of customer requirements and construction needs, leading to an incomplete or inadequate design solution.
Coding of Design Solution	Inaccurate representation of the design in drawings, descriptions, or models, such as incorrect details or omissions.	The intended design solution is correctly encoded, but the solution itself is inherently erroneous or incomplete.
Communication Channel (Transmission of Design):	Technical issues like data corruption or loss during the transmission of design documents.	Flawless transmission, but propagating errors from previous stages, such as transmitting outdated or incorrect design documents.
Decoding of Design Solution (Construction Process' Interpretation):	Misinterpretation or misunderstanding of the design documents by the construction process.	Correct interpretation of received design documents, but the documents themselves are flawed or incomplete.
Construction process	Errors in the physical construction process: E.g. implementation of the design, use of wrong materials, or construction faults; failure to recognise the need for additional information or clarification.	Correct execution of the understood solution, but the solution was misunderstood, degraded in transmission, inaccurately described the intended solution, or contained inherent design flaws.
Coding of Conscious Needs (Construction Feedback)	Inaccurate representation of the construction team's needs or issues.	The conscious needs are correctly encoded, but they do not represent the true needs of the construction process.
Communication Channel (Conscious Needs)	Technical issues in the transmission of needs, like data corruption or loss.	Propagation of errors from earlier stages, such as sending outdated or incorrect requests for information (RFIs).
Decoding of needs (Design Process' Interpretation)	Misinterpretation by the design process of the needs communicated by the construction process.	Correct interpretation of received needs description, but the description itself is flawed or incomplete.

By categorising errors in this way, we can more accurately pinpoint their origins and address them effectively. This categorisation can aid in distinguishing between errors arising from the inherent nature of a process (transformation errors) and those propagated from earlier stages (input errors), thereby facilitating a more targeted approach to mitigating communication errors in construction projects.

DISCUSSION AND CONCLUSION

This paper developed a conceptual model to serve as a framework for understanding and analysing communication errors at the interface between design and construction in production systems. Our approach integrated insights from three critical areas: production, communication, and design theory. This integration aimed to create a unified model that encapsulates the information flow dynamics between design and construction, an aspect not comprehensively addressed by existing models.

The DCCL model posits that the root cause of communication errors in construction projects often resides in complex causal chains. By dissecting these chains, the model helps academics and practitioners better comprehend and address these errors. The model can serve as a foundation for developing strategies and tools to identify and mitigate these errors, enhancing the efficiency and effectiveness of information flow between the design and construction processes. For example, we believe the model could be particularly beneficial for conducting root cause analysis of communication-related issues.

However, the DCCL model was developed using a purely conceptual approach. While we believe in its utility, empirical research is essential to ascertain its full applicability and effectiveness. Such research would involve validating the model in real-world construction projects and assessing its utility in identifying, analysing, and addressing communication errors. A crucial aspect of this validation is ensuring that the model has sufficient coverage to accurately capture and describe all communication errors across a variety of scenarios.

One known limitation in this regard is that the model focuses solely on the 'what' and 'how' of communication and does not consider the 'when.' Timing is a critical factor in the construction industry, where delays in communication can lead to significant inefficiencies and challenges (Gamil & Abd Rahman, 2022). Incorporating a temporal dimension into the model could provide a more complete understanding of communication dynamics in construction projects. However, doing so runs the risk of overcomplicating the model. A conceptual model is meant to “facilitate the comprehension or the teaching of systems or states of affairs in the world” (Greca & Moreira, 2000). Adding more aspects or details to the DCCL model likely makes it less suitable in this regard.

Nevertheless, excluding temporal aspects from the core model does not preclude their consideration in empirical research and practical applications. One possibility is to integrate the DCCL model with Value Stream Mapping, where each step of the DCCL could be mapped as processes or outputs on a value stream map.

In conclusion, the DCCL model presents a promising advancement in conceptualising information flow within construction projects. However, its potential to significantly impact the field hinges on rigorous empirical validation. The model's theoretical insights must be tested and refined through practical application and empirical research to ensure its efficacy and relevance in real-world settings. Such validation is crucial to substantiating the model's utility as a tool for enhancing communication and improving efficiency in the construction industry. This process will confirm its applicability and refine its components to better address the nuanced challenges faced by practitioners.

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