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# THE DUAL NATURE OF COMPLEXITY IN CONSTRUCTION MANAGEMENT– CALL FOR A RENEWED DEBATE

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## ABSTRACT

The paper is conceptual, with the aim of raising a new debate on complexity and value creation within IGLC. The topic of complexity in construction projects was first raised in the Nineties before it in the early 2000s was introduced on the Lean Construction and IGLC agenda. When facing a complex problem, there are two possible strategies to pursue with reference to the Cynefin framework for complexity. The first is to transform and move the problem into the complicated or even simple domain, thereby making it manageable. The second is to handle the problem within the complex domain. The dominant approach within both Project Management and Lean is the first, namely, to emphasize efficiency, flow, standardization, best practice, planning, reliability, and control. The paper challenges this lop-sidedness by pointing out its potential reductionism and argues that we should also appreciate, exploit, and take advantage of complexity instead of just combatting it. Value creation is reliant upon both strategies and is therefore not a question of either or, but of balance and trade-offs based on an inherent dualism.

## KEYWORDS

Complexity, complicated, Cynefin, value creation, design.

## INTRODUCTION

In the Lean Construction research community, there is a strong focus on approaches to control the design and production processes to achieve order, e.g., measured by percentage planned completed (PPC) as in Last Planner (Ballard, 2000a), and many of the contributions from IGLC-conferences on complexity are devoted to reduce complexity as a threat to stability and stable flows, see for example Dlouhy et al. (2018); Filho et al. (2016), Larsson and Simonsson (2012) and Al-Sudairi et al. (2000). Bertelsen (2003) took a lead role together with co-authors to publish on complexity in IGLC in the period 2003-2005 (Bertelsen and Emmitt, 2005; Bertelsen and Koskela, 2004). Bertelsen (2003) argues that project management must perceive the project as a complex, dynamic phenomenon in a complex and non-linear setting.

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A motivation for this paper is that we conceive complexity and interdependence also to be a source of value creation. Pennanen and Koskela (2005) are touching upon this idea when they conceive value generation, as in the TFV-model (Koskela, 2000), to address time-independent complexity. The early design processes are seen as inductive by Pennanen and Koskela (op cit.) since there are several correct or good answers. We share this ontological understanding of design, but we also see design as processes that do not just take place prior to the production phase, but often continue in parallel with production. Follow-up design is important in many projects and may be embedded in management styles that pursuit to take advantage of opportunities also in the execution phase (Johansen et al., 2019).

The Cynefin framework (Snowden, 2002) is a central conceptual point of departure for our reasoning on complexity. Snowden differentiates between the domains denoted simple, complicated, complex and chaos, where each domain has different characteristics and requires different management and leadership approaches (Snowden and Boone, 2007). A construction project in the chaos domain would be very demanding (Bertelsen and Koskela, 2003; Vrijhoef, 2004), but in innovation projects that is maybe the domain where we want to be for some period. In the complex domain we don't know the exact effect of actions, the impact emerges.

In construction one may regard the product being produced (the building, bridge, etc.) as being complicated rather than complex, as the parts can be identified and related in a BIM-model. The properties and behavior of the product can however also be complex, e.g., the ability of a bridge to tackle dynamic loads. The contextual conditions related to location, e.g., ground conditions and topography, may also turn a construction project over to the complex side, also conceived as a product. Complicated or complex, the social processes of engineering, design and maybe production, involving internal and external stakeholders, is likely to make it complex or add to the complexity already there.

Project management will typically give priority to order and predictability to deliver on time, cost and scope, especially in fixed price contracts. Also, for the Last Planner System for Production Planning and Control (Ballard, 2000), the aim is to achieve order prior to production (Filho et al., 2016), however in a way that has the capability to deal with uncertainty and emergence on the detailed level. Last Planner addresses the time-dependent complexity (Pennanen and Koskela, 2005) and is an operationalization of the flow model. It does however not have the capability to create customer value based on exploration of the opportunities embedded in complexity or uncertainty (Torp et al. 2016; Klakegg et al. 2020).

When we relate complexity and value, we address customer value, which includes the operation and maintenance phase. By (customer) value creation we mean the construction processes that leads to value for the direct client, the operators, and the end users. We address the value potential which comes in addition to the value identified in the project specification, the potential surplus value.

Our problem statement is to contribute to unpack the duality of complexity, being both a threat to predictability and a possible source of value creation. Increased understanding of this duality has a potential to improve the knowledge underpinning project management practices. Our discussion is focused on complexity related to construction projects. Complexity in manufacturing and in more general terms is only to a very limited degree touched upon.

The structure of the paper is as follows: After this general introduction we first introduce the Cynefin framework, before we present the discussions on complexity within

IGLC/Lean Construction and the broader search on construction projects. With this as input we address and discuss the dual nature of complexity in construction before we conclude.

# THE CYNEFIN FRAMEWORK

Cynefin is a framework for sense-making through a distinction between the four domains *simple*, *complicated*, *complex*, and *chaotic* (Snowden 2002). The simple domain is the domain of known, perceivable and predictable cause and effect relations. In the complicated domain things are still (at least in principle) knowable but causes and effects can be hard to comprehend due to quantitative or qualitative reasons. In the complex domain there are still cause and effect relations, but they are only coherent in retrospect and do not repeat. Finally, in the chaotic domain, the cause-and-effect relationships are not perceivable. The simple and complicated domains are characterized by *order*, while the complex and chaotic domains are characterized by *unorder* (Kurtz and Snowden 2003; Snowden and Boone 2007). A complex system is a system composed of interconnected parts that as a whole exhibit one or more properties, which behavior is not obvious from the properties of the individual parts. The system exhibits properties that are not evident from the properties of the single parts (Snowden, 2002).

There is an interconnection between the Cynefin domains, and the three types of interdependencies identified by Thompson (1967). Pooled and sequential interdependencies belong to the simple and complicated domains, while reciprocal interdependencies typically will be part of the complex domain. In reciprocal dependencies there is mutual interdependencies between the elements, creating a feedback situation where the behavior of any element is a precondition for other elements. There is also a relation between the Cynefin framework and the distinction between deductive and inductive systems (Pennanen and Koskela, 2005) and wicked problems (Churchman, 1967). Correct answers can be found to deductive problems. The answers can by easy to find, placing the problem in the simple domain or it can be more difficult to find, placing it in the complicated domain, but they can be found. The answer is in principle a calculation using known elements and therefore actually not producing new knowledge. Inductive problems belong to the complex domain. There might be several (correct) solutions to an inductive problem (no right or wrong) and new knowledge is produced (all information needed for the solution can’t be found in the initial information). Churchman (1967) calls these problems wicked and point out that they have no stopping rule and no ultimate best solution. The solutions can be evaluated qualitatively as good or bad but are not true or false.

# COMPLEXITY WITHIN IGLC AND LEAN CONSTRUCTION

A search at IGLC.net returned 104 matches on “complexity” and 237 matches on “complex”. Especially in the period 2003-2005 there was a focus on complexity encouraged by the work of Bertelsen and co-authors. Bertelsen (2003) called for a new way of understanding and managing construction processes (organizing, planning, and control) based on complexity theory. A complementary contribution by Bertelsen and Koskela (2003) addressed how to avoid chaos in construction projects. They state that construction projects are often very complex and dynamic by their nature, and it is a “well-known fact that such systems exist on the edge of chaos”. They explore the forces that may turn projects to cross this “dangerous edge” to chaos. Such forces are rework and parallelism in design. Last Planner, they say, seems to be a useful tool to control chaos-in -the small (firefighting), while it is a more open question of how to control chaos-in-the-large, chaos which is a threat to the whole project. Bertelsen and Koskela (2004) explain more in detail their work from 2003. Bertelsen and Emmit (2005) address the client as a complex system. They suggest a research agenda to improve understanding by applying value management alongside contract management and production management.

Kenley (2005) characterizes complexity in construction as a myth and criticizes the referred work by Bertelsen and Koskela. He argues that it is the activity-based planning (CPM) that leads to chaos, and that the problem and solution is one of mathematic. Kenley's solution is to pre-plan location-based and to establish a factory production set up on site. He argues that control systems of late intervention such as Last Planner are then not necessary.

Vrijhoef and Tong (2004) argue that construction environment should be understood as complex adaptive systems, which need to be adaptive to changes from both inside and outside the system. The management challenge of adaptive networks is to balance a minimum level of predictability and controllability and a maximum level of flexibility and emergence.

Bertelsen (2003), Bertelsen and Koskela (2003, 2004), Bertelsen and Emmit (2005) and Kenley (2005) do not differentiate between design and production. Lima et al. (2011) discuss complexity in design related to BIM. The authors argue that despite the complexity of design processes, simplistic thinking like BIM is needed. To support this, they refer to the distinction of Pennanen and Koskela (2005) between necessary and unnecessary complexity in construction.

Pikas et al. (2015) differentiate between production (construction) and design regarding process complexity, as design problems are inductive in nature and that there is no single best answer or "best way", while production is deductive and a "best way" is possible (Pennanen and Koskela, 2005). Theoretically, it is argued, construction can be developed with sequential or concurrent tasks. From this they deduce that complexity is rather self-inflicted and caused by organizational structures and people, an argument that is strengthened by reference to Tommelein (2015). The Design Structure Matrix is applied for mapping and modelling purposes. What makes design complex is that tasks are coupled (Wynn, 2007), simultaneously needing input from each other. Moreover, they discuss how process and organizational complexity can be reduced using concurrent engineering in organizational settings known as "big rooms", "extreme collaboration" (Chachere et al., 2003) and "Obeya room" (Morgan and Liker, 2006). Pikas et al.'s ontological understanding of design gives resonance to wicked problems in design, which is addressed by Whelton and Ballard (2002), Kalsaas (2020) and Lane and Woodman (2000).

Most of the papers reviewed so far see complexity as a threat to the construction processes. Other examples of this line are Ramírez-Valenzuela et al. (2021); Al-Sudairi et al. (2020); Dolphy et al. (2018); Filho et al. (2016); and Larsson and Simonsson (2012). Several contributions use the term complexity as a self-evident term (e.g., Al-Sudairi et al., 2020). Intuitively we understand and accept that a hospital project is more complex than a housing project. Pikas et al. (2015) characterize complexity as a vague term. Filho et al. (2016) refer to the Cynefin framework and make a distinction between complicated and complex. Biton and Howell (2013) argue that the Cynefin framework can be highly useful for people working in construction projects and that it should be taken on board as one of the theoretical foundations of Lean Construction. Their argument has this far only been followed up in a few IGLC papers.

## OTHER LITERATURE ON COMPLEXITY IN PROJECTS

Pennanen and Koskela (2005) referred to above, arguing that to create value and manage time and cost, project management should promote complexity when needed, and reduce complexity, when it is unnecessary. They relate necessary complexity to the commitment making process among the whole variety of stakeholders. Unnecessary complexity is exemplified by the separation of programming and sketch design to eliminate complexity. Design is understood as an inductive process, and it is differentiated between inductive and deductive complexity. Regarding design for production (detailed design) they claim that the "right answer" is known (from pre-design), and that complexity therefore switches to become deductive.[4]

Baccarini (1996) is recognized to be an early contributor on complexity related to projects (Rolstadås and Schiefloe, 2017; Bertelsen, 2003). He differentiates between organizational and technological complexity analysed from the perspectives of differentiation and interdependencies. When it comes to technological complexity the differentiation is seen as a function of the number and diversity of inputs/outputs, tasks to be produced and the number of specialties involved necessary to design and build the artefact, when relate to construction. The interdependencies in technological complexity can be related to the interdependency terms developed by Thompson (1967) where reciprocal interdependencies between tasks, technologies and stakeholders create uncertainty and call for iterations in design (Kalsaas, 2020). Organizational complexity is defined by the number of organizational units, relations between these and the kind of tasks the units are handling. Williams (1999, 2002) introduces structural complexity by combining Baccarini's technological and organizational complexity and adds uncertainty as a second main component, in which uncertainty in goals and methods are addressed.

Hass (2009) understands complexity in term of characteristics that make a project unpredictable and dynamic. Brady and Davies (2014) conceive dynamic complexity in projects to be a function of changing relationships between system components and between the project and its environment and has to do with unpredictable situations and emergent events that occur over time. They make a distinction between dynamic and structural complexity. Structural is seen as the arrangement of components and subsystems in the overall systems architecture, which comprises the system produced, the producing system and the wider system. The system produced is the delivery of the product. The producing system contains a technological (the process of producing) and an organizational part (the project organization), whereas the wider system includes the owners and the users of the produced system. A project can have a degree of structural complexity with a low level of dynamic complexity and the other way around. Hence the two complexity dimensions may occur independently. Whitty and Mayor (2009) relate complexity in projects to system thinking and define a complex system to be a system formed out of many components whose behavior is emergent.

Luo et al. (2017) address research trends regarding complexity in construction project. They identify influencing factors contributing to project complexity, the impact of project complexity, complexity measurement methods, and considerations for managing project

[4] Pennanen and Koskela (2005) do not distinguish between complicated and complex. Parts of their reasoning on "complexity" can be read as what is in the Cynefin framework called "complicated".

complexity. They argue that future research should concentrate on specific factors that drive complexity throughout the lifecycle for different types of construction projects, and to develop management guidelines for handling the complexity.

There is a direction in project complexity research which aims to establish a model to assess project complexity and to align the project organization to handle the complexity at hand. Rolstadås and Schiefloe (2017) have developed such a model, and argue that project complexity is a function of project characteristics and the organization managing it. Their model operates with generic drivers and surroundings (contextual factors) which may influence the drivers and complexity factors, which are conceived to be project specific. The identified drivers based on literature research are ambiguity, uncertainty, unpredictability, and pace. The surroundings are categorized into socio-political, economic, technological, and nature. Nature represents a source of uncertainty in any project. It may lead to complexity in execution and has impact on the project organization. The complexity factors include the project context of internal and external stakeholders, the project organization, production technology (the producing system) and the system produced, confer Brady and Davis (2014). The social and cultural dimensions are embedded in the project organization.

# DISCUSSION

While Cynefin makes a distinction between complicated and complex, much of the literature on "complexity" does not. It can therefore be observed that when discussing "complexity", parts of literature is in fact addressing the Cynefin domain of the complicated. What is in literature referred to as technological complexity often belongs to the complicated domain in Cynefin. However, if the levels of innovation are high, it can also be complex. What is referred to as dynamic complexity certainly belongs to the complex domain also in Cynefin.

The literature addressing complexity in construction projects is mainly focusing on complexity as a threat to predictability and successful execution. It focuses on procurement models, execution models and tools that can enhance the project's ability to identify, reduce and handle complexity.

Pennanen and Koskela (2005) differentiate between necessary and unnecessary complexity. They do not conceive complexity as a possible source of value generation. Instead, they promote the importance of resolving programming prior to sketch design. This is an approach to reduce complexity and may be counterproductive for value generation, confer our discussion below about the dual nature of complexity.

Pikas et al. (2015) address process complexity, applying the Design Structure Matrix (DSM) for mapping and modelling. DSM is instrumental to reveal interdependencies ex ante, but we claim that this mainly belongs to technological and product complexity. Processes also include the social dimensions and therefore the world of emergency. It might be possible deductively to design processes ex ante, but design is best understood to be ontological inductive as argued above with reference to Pennanen and Koskela (2005). Hence, some important aspects of complexity in projects are difficult to identify ex ante because people are important contributors to complexity. It is however possible to predict complexity through analysis and experience, using approaches like the model developed by Rolstadås and Schiefloe (op cit.). Such predictions can be useful when designing project organizations. Moreover, if complexity is well understood by management and the project organization, they can better reflect on which decisions and behaviours are likely to increase complexity, making them able to make a trade-offs between predictability and order on the one hand and possible value creating potentials and costs on the other. We address this duality below.

## THE DUAL NATURE OF COMPLEXITY

A central dimension of duality we address in this paper is that between complexity as a threat to predictability and complexity as a source to value creation. The threat argument is apparent from the literature review above. In IGLC papers and in the broader literature search in the construction literature we have not identified the idea that complexity may be applied as a source of value creation.

The value creating argument needs to be developed, especially in relation to design. Koskela, et al. (2013, p. 9) see "the design-production-use process as a chain where the value is created as a potential in design, is embodied in production and is realized in the intended use by the client". Hines et al. (2004) argues that most of the potential for value creation is found in design, and that in fact all changes of design, even if they are initiated from production, will account as value creation in design or development of customer value.

When it comes to complexity and value creation, we will take the point of departure in the tradeoff between the drive to freeze solutions in design to create order and predictability versus the drive to postpone (Yang et al., 2004) the decision to explore alternatives as in set-based design (Ward et al., 1995) with the aim of creating surplus customer value. However, postponement and set-based design strategies are likely to increase structural complexity (Williams, 1996) as the number of interdependent variables and issues increase. Zinn (2019) argues that set-based design decisions normally decrease uncertainty (Yang et al 2004), due to higher maturity, understanding, and the involvement of more trades in the decision.

The idea of postponement is related to the concept of the Last Responsible Moment (LRM)., defined as "the instant in which the cost of the delay of a decision surpasses the benefit of delay" (Senior, 2012). Ballard (2000b) argues that customer value might be increased by deferring design decisions until the LRM. The mechanisms underpinning this are learning and gradually increased understanding of what is being created. Working with different sets of alternatives is likely to encourage and increase the learning by the client and end-users if they are involved in the decision-making process. We prefer, however, to apply the postponement term instead of LRM, as we regard it to be practical impossible to identify a specific LRM.

As the project proceeds the customers will learn and increase their understanding of the project and its impact and their plans for usage may change, leading to changed needs and priorities (Boyd and Chinyio, 2006). Eikeland (1998) uses the well-known increase in accumulated cost and decrease in uncertainty during the execution of the projects due to freezed design and work completed to demonstrate that this creates an increasing gap between the needed/wanted and available freedom of action, limiting the ability to make changes. We have identified uncertainty as an important driver of complexity and can therefore replace uncertainty with product complexity in this model, demonstrating that as complexity decreases, so does the ability to make needed/wanted changes. Set based design and postponement of decisions are strategies to reduce this gap.

We apply the term product complexity, which in our conceptualization is the same as technological complexity. When the design develops and matures it becomes less complicated as the number of interfaces and interdependencies between disciplines and other actors is reduced. However, design is at its hart people creating something new. (If nothing is new, there was nothing to design.) Design will therefore always have an element of emergence, handling reciprocal interdependencies, possible ambiguity, unpredictability, uncertainty, and pace (Rolstadås and Schiefloe, 2017). It will therefore also always have at least a degree of complexity. Size also matters. It is e.g., far more challenging and potential complex to coordinate or lead the work of 100 engineers and architects compared to 10.

To avoid the domain of chaos, all decisions in design can of course not be delayed. The project needs to identify certain strategic decision to be object of set-based design, e.g., the decision of when to freeze the room schedule of a building. When the room schedule is frozen, the product complexity is reduced. But the freedom to explore new opportunities for value creation is also restricted. As an example, an evaluation study of a new world class animal hospital project with significant cost overruns, indicates that late decisions of the room schedule contributed to chaos in design (Kalsaas et al., 2020). The delay was mainly caused by late decisions by the end-users who wanted to take advantage of world class equipment and facilities for the hospital. It may make a huge difference for the design processes if postponement and delay is planned or if it just emerges.

The strategy of increasing complexity to enhance value creation can also be related to uncertainty management (Klakegg et al. 2020). Uncertainty comes with both upsides (opportunities) and downsides (risks or threats). While risk management has a sole focus on avoiding downsides, uncertainty management advocates a balanced focus on exploiting upsides and avoiding downsides. The first is an often-unexploited potential in both the design and execution phase (Johansen et al., 2019). The opportunity part of uncertainty represents a potential to harvest surplus value. In the hunt for opportunities, it may be worth the risk to increase complexity, e.g., by postponing design decisions. Malvik et al., (2021) relate the concept of uncertainty and opportunity management to the concept of Target Value Design/Delivery (TVD) (Ballard, 2020). In TVD the approach is to maximize value delivery within a cost constraint. This in contrast to traditional bidding where the approach is the opposite, to minimize the cost of a predefined value delivery.

Relational construction contracts seem to gain ground in replacing transactional contracts as design-bid-build and design-build. Integrated Project Delivery (IPD) is one of several relational contract models (Lahdenperä, 2012; Mesa, 2019) well known in the Lean Construction community. The aim of IPD is to improve collaboration and remove sub-optimalisation by aligning the interests of the parties. This is done through a multiparty contract between the client, the designers and one or more construction companies. Central elements of the contract are open books, limited liability for the parties, sharing of profit and risk, and joint decision making. These are all elements that increase complexity. E.g., Kalsaas et al. (2020) studied an IPD hospital project and found that the project organization were struggling with the decision making. IPD projects are usually founded on a TVD approach where the parties in the initial phase collaborate on design and cost estimation to agree the target price as a precondition for signing the final contract of execution. This initial phase is complex due the nature of design and the number of decision makers, but also because the economic interests of the parties are not yet aligned (Kalsaas et al., op cit.). The client may want a low target price, while the construction companies want a high target price to reduce their risk. Even if the economic risk for the contractors is limited in IPD it is a severe blow for companies to be working on a major project for several years without any return on capital.

Closing this discussion of IPD and complexity we summarize that in IPD projects complexity is increased to create surplus value. At the same time the project organization is designed to, or should be designed to, cope with the complexity created.

# CONCLUSION

Literature on complexity in construction projects is focused on how to diagnose levels and types of complexity and which strategies to apply to cope with it. Several complexity terms and models have been developed, e.g., technological complexity, product complexity, dynamic complexity, and organizational complexity. Complex system may exhibit properties that are not evident from the properties of the single parts and a central aspect of complexity is emergence. Something emerging can only be identified ex post. In contrast to the Cynefin framework, parts of literature do not distinguish between complicated and complex.

The Cynefin framework differentiates between the four domains, simple, complicated, complex and chaos and represents a breakthrough when it comes to understanding complexity and how to approach it. Taking the Cynefin terms as point of departure, we have in this paper discussed aspects of complexity that are central to design and production in construction in general and to value creation.

Our literature review demonstrated that the debate on complexity in IGLC in the early 2000s conceived complexity as a threat and construction as being at the edge of chaos. When facing a complex problem, there are two possible strategies to pursue. The first is to transform and move the problem into the complicated or even simple domain, thereby making it manageable. The second is to handle the problem within the complex domain. The dominant approach within both Project Management, generic Lean and Lean Construction has been the first, namely, to emphasize efficiency, flow, standardization, best practice, planning, reliability, and control. One of the most recognized products of Lean Construction, the Last Planner System (LPS), can act as an example: LPS is designed to create predictable flows, mainly by reducing complexity (e.g., through phase scheduling and look-ahead planning), partly by handling it (through collaboration and short-term planning).

We have argued that the dominating approach to complexity as a threat is somewhat lopsided and potentially reductionistic. We therefore call for a renewed debate within Lean Construction on how we could also appreciate, exploit, and take advantage of complexity instead of just combatting it. Humans and cultures are complex by nature and learning, understanding and the creation of something new (that is design) are complex phenomena. Value creation is reliant upon both strategies and is therefore not a question of either or, but of balance and tradeoffs based on an inherent dualism.

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