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WHAT IS THE COMPLEXITY OF PRODUCTION PLANNING AND CONTROL?

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ABSTRACT

Questionable project performance is a common issue in the Architecture, Engineering and Construction industry, with one contributing factor being the degree of difficulty or complexity of the project. One effective approach to address this issue is to improve the system of production planning and control (PP&C). This strategy, as per the literature, had evolved to include up to four different types of PP&C mechanisms that are related to ´business´, ´production´, ´virtual´, and ´complex´ aspects. Nonetheless, despite the progress, PP&C still disregards various complexity-related aspects. To address this issue, we analyzed the concept of the ´*Complexity of PP&C*´. This paper discusses its definition, elements, and role. It was found PP&C complexity involves three aspects: project complexity, outcomes complexity, and structural complexity. Thus, we conceptualized PP&C complexity as a feature of the behaviour of outcomes that emerge to answer project stimulus driven by the interaction between the elements of the structure of PP&C, a feature that is both a risk and an opportunity for performance improvement. This perspective offers new insights for PP&C evolution and improvement, although further work is still required.

KEYWORDS

Production planning and control, complexity.

INTRODUCTION

Projects in the architecture, engineering, and construction industry frequently demonstrate poor performance. For example, Flyvbjerg et al., (2003, 2004) studied a sample of 258 infrastructure projects worth US$90 billion and found persistent cost escalations of between 20% and 45% that were strongly correlated with the duration of the project implementation.

In this regard, one significant factor that contributes to project duration is complexity. It influences negatively performance, as noted by Baccarini (1996), Floricel et al. (2016), Luo et al. (2017), and Williams (1999). For instance, complexity is often understood as the level of difficulty encountered during project implementation, although terms such as challenging, unstable, or unpredictable are also used to characterize it (Brockmann & Girmscheid, 2007; Gidado, 1996; Jarkas, 2017; PMI, 2013).

On the other side, one effective strategy to face the poor performance of projects relies on improving the system of Production planning and control (PP&C). The PP&C is a system which aims to transform ´intended´ into ´realized´ outcomes during the project(Ballard & Howell, 1998; Mintzberg, 1978). According to Burbidge, (1990) it *"... plans, directs, and controls the material supply and processing activities*". To do so, the PP&C relies on the use of a mechanism implemented using a set of managerial processes (e.g., planning procedures, meetings,

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etc.)(Marks et al., 2001). In turn, these managerial processes relate the strategic and operational activities while trying to create conditions to deploy and drive the construction operations, where consistent work of PP&C improves operational productivity and project performance (Ballard & Tommelein, 2021; Liu et al., 2011).

Figure 1 depicts the causation of a generic model for PP&C. This model involves two main parts: outcomes and system. The PP&C outcomes refer to the production aspect, which includes the final physical product or deliverable, the construction operations and its features (e.g., labour productivity, the propagation of variability, etc.). In turn, the PP&C system describes the managerial aspect which drives the PP&C outcomes. The system receives the stimuli from the project context, inputs (e.g., information on resources, labour, tools, methods, etc.) and feedback from the performance details of operations and progress. The structure of this system involves the use of an internal mechanism(s) which is set by the use of a particular model for PP&C (e.g., the Last Planner System, Critical chain, etc). Finally, the PP&C system generates an output (which involves streams of orders, weekly assignations, etc.) that drives the outcomes and could be considered part of them.

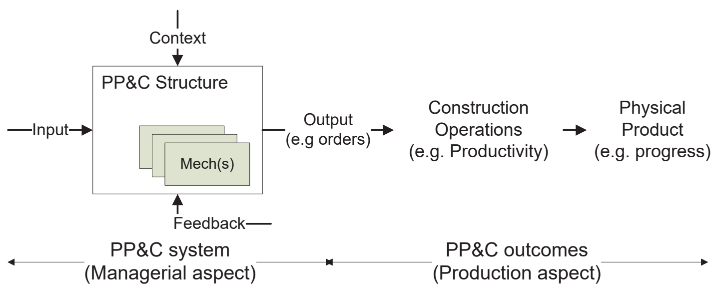

Figure 1: General causation of PP&C (for the construction stage of projects) (Zegarra 2021)

The literature suggests that PP&C use could be categorized into four types of mechanisms. The classification is based on the features and emphasis of the managerial processes used to implement the PP&C system and includes the following categories: business, production, virtual, and complex, which are complementary rather than optative(Zegarra, 2021). The business category emphasizes the use of economic/contractual processes, the production category focuses on processes for handling the workflow, the virtual category emphasizes processes for the use of virtual construction, BIM, Digital twins, etc., and finally, the complex category highlights the existence of processes for handling the interdependences between the elements of PP&C (Ibid). Thus, these categories suggest an evolution effort to improve the capabilities of PP&C and in consequence the performance of projects.

Nonetheless, despite the progress observed, the evolution of PP&C still disregards various aspects related to complexity. Where complexity is understood as a feature of the mechanism of PP&C, which emerges from its outcomes and structure. The complexity of the outcomes refers to behaviour features observed in the inputs, such as the propagation of variability (Pereira et al., 2013; Zegarra & Alarcón, 2017). Whereas structural complexity refers to the organization of a set of interdependent elements from social and process domains and their related emergent featuresover time (e.g., Zegarra & Alarcón, 2015, 2019).

In the face of an evolving AEC industry where the complexity of projects is ever-growing, the cost of doing nothing about the complexity of PP&C implies accepting both a risk and a missing improvement opportunity. For instance, Flyvbjerg, (2014)suggested that projects have moved into the TERA projects era due to the scale of their costs far beyond mega projects. Thus, this condition raises the following question:

What is the complexity of PP&C?

Thus, this study´s goals are: (1) To develop a PP&C complexity model (for the construction stage). (2) To provide a baseline theory useful for analytic generalization.

This article is organized as follows: First, the background section reviews key concepts on PP&C and Project Complexity. Then some relevant insights on the methodology are presented. After, the results section presents two models which help to describe the concept of complexity of PP&C. Finally, the main implications of the concept are discussed and conclusions are drawn.

BACKGROUND

DEFINITION OF PP&C

The PP&C plays a crucial role during project delivery, it is the system that governs the deployment of construction operations and the attainment of project goals. According to Ballard & Howell (1998) in the AEC industry, the PP&C system often is depicted as the preparation and control of schedules and their related budgets at the project level. For instance, the creation of as-planned schedules and their comparison against as-built schedules. Modern PP&C systems have been redefining this view, by describing it as a hierarchical and collaborative planning system, which involves several stakeholders and spans various levels, from operational to strategical (Ibid) or as a system enabled by the use of BIM (Schimanski et al., 2020).

According to Zegarra (2021), the literature suggests the existence of four approaches to the definition of PP&C, as the examples in Table 1 shown

Table 1: Selected definitions of PP&C (Zegarra, 2021)

View	Definition
Business	"*Project planning and control have as its broad and overall objective the prescribing and field attainment of an orderly progression within budget and time, toward the completion of project facilities."* (Halpin & Woodhead,1980 p293)
Production	*"Construction production and control can be usefully conceived and represented as consisting of three hierarchical levels roughly corresponding to … (1) aggregate production planning; (2) material coordination and work-load capacity; and (3) work order release and production unit control … the levels are (1) "initial planning"… (2) "lookahead planning", " … and (3) "Commitment planning"… "* (Ballard & Howell, 1998 p11)
Virtual	"*BIM-based production management system … is characterized by a theoretical integration model for BIM and existing construction management techniques …"* Schimanski et al., 2020 p1*)*
Complex	*"[Project control feedback structures] are managerial decisions and actions to correct poor project performance during project execution. Project controls can include process improvement, adjusting performance targets, change management, and resources management"(* Taylor et al., 2007 p1*)*

In this context, this work uses the following definition of PP&C, which is a synthesis of the definitions found in the literature:

> *´the PP&C is a Project´s function which aims to transform intended into implemented outcomes, to do so, it uses a system that interacts with the project and which relies on a particular causal mechanism(s) (e.g, a set of managerial processes), to transform strategy into operational actions through the interaction*

> *of persons, information, decisions, actions, processes, and technical resources while generating managerial throughput (e.g., weekly instructions)and emergent features (e.g. variability), which in turn drives and influences the deployment of construction operations over the project course´ (Zegarra 2021 p 17).*

PROJECT COMPLEXITY

Complexity is a critical characteristic which influences the performance of projects. Over time its ever-growing magnitude has exposed the weakness and limitations of the managerial methods used for project delivery (Baccarini, 1996; Floricel et al., 2016; Luo et al., 2017; Williams, 1999). For instance, it influences the required levels of planning, coordination, and control, where higher complexity levels impact negatively, time, cost and quality performance (e.g., Baccarini, 1996; Floricel et al., 2016)

The definition of complexity Involves the existence of various aspects. In this work, complexity is understood as a "*property according to which, aspects such as the interactions between elements within a system structure, dynamical trends in the behaviour of its outcomes, emergent and unexpected features …., and uncertainty play a crucial role in the behaviour of the system* (e.g., Boisot & McKelvey, 2011; Dooley & van de Ven, 1999)" (Zegarra 2021 p2).

In this context, emerges the definition of *project complexity.* Although there is a lack of consensus, the concept can be described using the selected terms in Table 2:

Table 2: Project Complexity (Zegarra, 2021)

Definitions
"*The degree of difficulty faced during the execution and fulfilment of work activities and objectives over the project course* (Brockmann & Girmscheid, 2007; Gidado, 1996; Jarkas, 2017)*"* (Zegarra 2021 p3)
" A project´s feature ´… "consisting of many variated interrelated parts" and can be operationalized in terms of differentiation [of elements] and interdependency´ (Baccarini, 1996; Luo et al., 2017)*"* (Ibid)
" A feature characterized by two aspects ´… [i] structural complexity, [i.e.] the number and interdependence of elements (following a paper by Baccarini) … and [ii] uncertainty in goals and means (following a paper by Turner and Cochrane)´(Williams, 1999 p269)*, where interaction and emergence drives a structural complexity which includes uncertainty* (Cristóbal, 2017)*"* (Ibid)

The interest in project complexity has grown during the last two decades, nonetheless, its use as part of the regular arsenal of methods available in projects is under development. According to the literature (Baccarini, 1996; Cristóbal, 2017; Floricel et al., 2016; Luo et al., 2017; PMI, 2013), among the aspects currently studied, are its importance, the awareness of its role, its elements, measurement, impact, and management, where the main findings include:

- Key drivers: team and technological complexity
- Measurement: Based on conceptual frameworks (e.g., surveys) but it still lacks robust approaches (e.g. using interactions, dynamics, etc.)
- Impact: It affects negatively project performance
- Approaches currently used to face it: risk management, style of management, and capacity for adaptation.

METHODOLOGY

This study aims to provide *a preliminary theory* for future study of PP&C. To do so, it builds a mechanistic explanation (Hedström & Ylikoski, 2010) that uses a set of models and theoretical propositions to address the features of PP&C complexity. This reasoning uses the findings of (Zegarra & Alarcón, 2017, 2019) and Zegarra (2021) and concepts from a Language Action Perspective (LAP)(e.g.,Winograd & Flores, 1986), Lean Management (e.g., Koskela et al., 2002), and Complex Adaptive Systems (CAS) (Boisot & McKelvey, 2011).

The methodology follows the case study logic to state the role of the theory it aims to develop. Thus, following Yin, (1994 Chp 2), this work builds a baseline theory useful for guiding future inquiry on the complexity of PP&C (Figure 2a, step 1). The baseline, in turn, will be tested later throughout future empirical data analysis (Ibid).

The baseline theory provides a mechanistic explanation. In this regard, it focuses on building models to depict the "*cogs and wheels of the causal process through which the outcome to be explained was brought about*" (Hedström & Ylikoski, 2010 p50). Thus, the explanation integrates observations on the PP&C work, previous studies, LAP, Lean, and CAS concepts to build two models. Figure 2b describes the reasoning process used to develop the explanation (Pauwels and Di Mascio 2009).

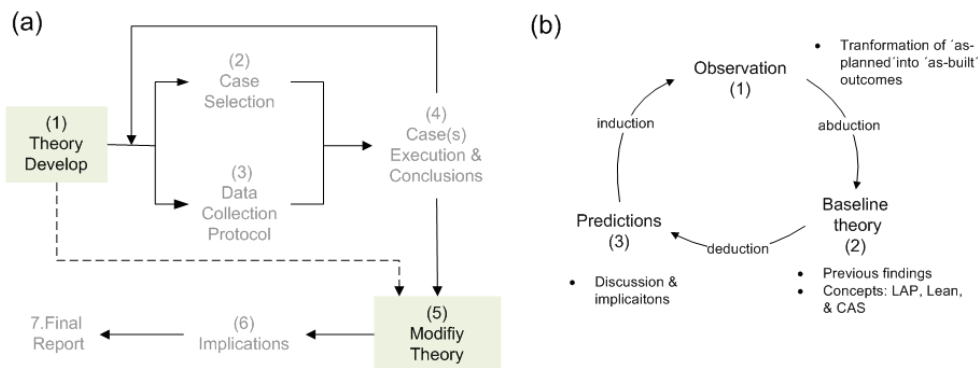

Figure 2: Research methodology: (a) Baseline theory role; (b) theory-building approach (After Pauwel and Di Mascio 2009 p13)

The following assumptions on the mechanistic explanation must be noted: First, it conceptualizes human action using LAP. Then, it uses a Lean view to model the value stream of PP&C. Finally, using CAS tools and concepts it describes the behaviour of outcomes. The CAS tools and concepts include the "Ashby Space" (Boisot & McKelvey, 2011), the *´law of requisite complexity´* (Ashby, 1957; Boisot & McKelvey, 2011), variability propagation concepts (Zegarra & Alarcón, 2017) and complex adaptive ideas about PP&C modelling (Zegarra & Alarcón, 2019).

PP&C COMPLEXITY MODEL

The following models describe the different aspects of PP&C complexity. The first model (Figure 3) describes a general view of the causation enabled by the PP&C, highlighting its complexity-related elements (e.g. emergent features, feedback linkages, etc.). The second model (Figure 4) describes the behaviour aspects of the relationship between the complexity of the project and the complexity of the PP&C system and outcomes.

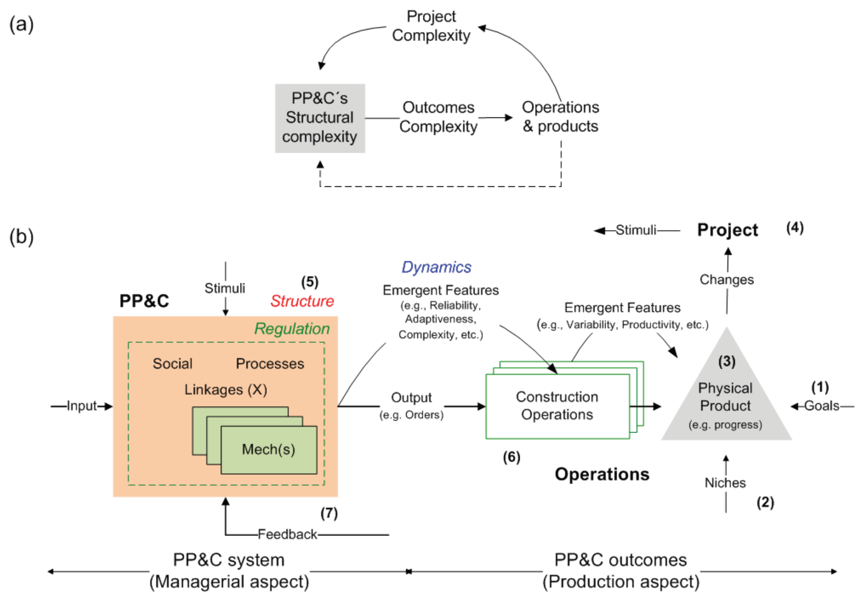

Figure 3: General causation of PP&C and its complexity features (After Zegarra 2021)

GENERAL CAUSATION MODEL

The model in Figure 3 describes the relationship between PP&C, Operations and Project. The model considers them as three coupled and hierarchical systems. The Project level is the most external, while PP&C is the most internal. At the Operations level, the outcomes of PP&C answer project stimuli. In this way, the complexity of PP&C can be divided into three related categories, project complexity, structural complexity, and outcomes complexity (Figure 3a). Figure 3b details the different aspects of the relationship, explained as follows:

Project complexity describes any element located beyond the construction operations level but within the project´s boundary. For instance, engineering, procurement, etc. or any other aspect carried out as part of the project

Structural complexity describes an attribute of the PP&C system´s structure. It includes elements from social and process domains, the linkages between elements, emergent features, and mechanisms used to provide managerial causation. The handling of the structure during the project involves a regulatory effort.

The outcomes complexity describes the behaviour attributes of the PP&C outcomes. These include managerial output (e.g., the emission of orders, weekly assignations, etc.) and its associated emergent features (e.g. the assignations´ reliability), the deployment of construction operations and their related emergent features (e.g., their productivity, variability, etc.), and finally the generation of physical products. The model names the managerial output and the emergent features as dynamics

Finally, the model depicts a progressive adaptation process of PP&C, operations, and projects. Thus, following Ellis (2008), to attain a certain goal (1) (e.g., an as-planned goal), the PP&C outcome fulfils a certain behaviour niche (2), through the generation (6) of a physical product (3) (e.g. an as-built result), all of these steps generate feedback (7) on the structure of PP&C. Step 3 introduces a change in the project´s conditions (4), which in turn generates a new stimulus that influences the operational level and the PP&C structure (5). Given the hierarchical and coupled nature of the model, the adaptation process suggests a double-loop interaction (Sterman, 2000). The internal loop involves PP&C and operations, whereas, the external loop involves the operational and project levels. This mechanism may drive the co-evolution of PP&C, Operation, and Project over time.

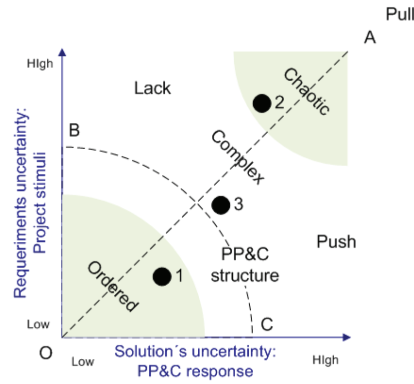

Figure 4: Relationship between Project and PP&C (after Zegarra and Alarcón 2019)

BEHAVIOUR MODEL

Figure 4 presents a behaviour model for PP&C complexity. It relates project complexity and PP&C complexity aspects (Figure 4). The model also provides insight from a lean perspective, based on a comparative ratio between stimuli and response.

Figure 4a describes the relationship between the complexities of the project and its PP&C system. Thus, following Boisot & McKelvey (2011): The X and Y axes describe the project stimuli and the PP&C responses respectively (e.g., in practical terms, these axes could use as stimuli data from as-planned schedules and as response as-built schedules data); The curve BC describes the boundary of the PP&C structure; The line OA describes a state of equilibrium between stimuli (Y) and response (X); Each black dots describe a pair of values x,y over X and Y axes; Finally the space also depicts three potential states of behaviour: ordered (i.e., linear and regular), chaotic (i.e, random) and complex (i.e., a transition between the previous two states and which mix their features), where for instance the relationship x,y for the dot 2 exhibits chaotic behaviour.

In addition, the model in Figure 4 also provides a behaviour insight from a Lean perspective. Thus, following Zegarra & Alarcón (2017, 2019): OA reveals an ideal pull relationship between Project stimuli and PP&C response (i.e, response/stimuli = 1), whereas the areas OAX (below OA) and OAY (above OA) respectively depict “push” (i.e., response > stimuli) and “lack” (i.e., response < stimuli) behaviours for each pair of x,y values. This interpretation is based on the behaviour of a divisive ratio used to express the nature of the activity between stimuli and response, for an x,y point over a two-dimensional diagram (Lindemann et al., 2009 p202). Finally, as a summary, it can be said for instance, that dot 3 is located beyond the structure of PP&C, and exhibits a complex behaviour, with a push relationship between stimuli and responses.

DISCUSSION

This study aims to provide an answer to the question, what is the complexity of PP&C? To do so, it presents a model that depicts and explains the nature of this concept. The complexity of PP&C is understood as a characteristic that influences performance and that involves three aspects: ´outcomes complexity´, ´structural complexity´ and ´project complexity´. The model developed in this study depicts the complexity of PP&C as a relationship between project complexity (stimuli) and the complexity of PP&C outcomes (responses), a condition which in turn is regulated by the structural complexity of PP&C. This relationship may behave exhibiting an ordered, chaotic or complex regime. The complexity of PP&C reveals both, a risk and an opportunity for PP&C performance and improvement.

The complexity of PP&C is a behaviour feature. In this regard, it could be observed in *´the behaviour of outcomes that emerge to answer Project stimulus, outcomes which in turn emerge driven by the interaction pattern between the elements of the structure of PP&C´* (Zegarra 2021 p17). This understanding involves the presence of three aspects: *´project complexity´* (i.e., the behaviour beyond the boundary of PP&C), *´outcomes complexity´* (i.e., the behaviour pattern observed in the PP&C outcomes), and *´structural complexity´* (i.e, the hierarchical organization of interdependent elements which configure the PP&C system). The complexity of the outcomes and structure are behaviour features of the mechanism used to provide PP&C in the project. This mechanism relies on the implementation of a managerial system which in turn drives the generation and deployment of various types of outcomes. This causation generates an interaction with the project through a progressive adaptation.

Project complexity describes the behaviour beyond the boundary of PP&C. It includes a set of interacting elements, which in turn, can be understood as complex adaptive systems (Choi et al., 2001). These elements interact with the PP&C over the project.

Structural complexity is an emergent attribute of PP&C. Where the structure refers to the set of interrelated elements used to implement the system driving the outcomes. Thus, the complexity of the structure describes a hierarchical organization of interrelated elements from social and process domains (e.g., team members, managerial processes, meetings, etc.) and emergent features organized to provide the PP&C.

Outcomes complexity is a behaviour pattern in the outcomes of PP&C. These outcomes may include managerial throughput, construction operations deployment, physical products or deliverables, and emergent features. The complexity of outcomes is a feature observable over the dynamic behaviour of these elements. For instance, if the managerial throughput (e.g. the set of weekly assignations) is understood as a stream of conversations used to guide the deployment of the operation, the behaviour of this stream may exhibit ordered, chaotic or complex behaviour features.

The complexity of PP&C involves an interaction between the project and PP&C. Figure 4 represents different degrees of the state of this interaction using black dots. The stimuli (Y-axis) on PP&C represent the project complexity, whereas the response from PP&C represents its outcomes complexity (X-axis). The relationship between response and stimuli is constrained by the structure of PP&C. This relationship exhibits different degrees of behaviour which span from an ordered regime, up to a chaotic one, passing through a complex state.

The model also provides insight into the behaviour of PP&C using a lean perspective. According to Lindeman (2010), over a two-dimensional diagram, a divisive ratio expresses the level of activity between stimuli and response.

The ideal behaviour for the complexity of PP&C may emerge within its structure boundary when this is located in the complexity zone close to the edge of the chaotic zone. The following reasoning elaborates on Boisot and McKelvey (2011) to explain the behaviour of PP&C: The regulation of the system structure is dynamic and involves a change of form and position. For the PP&C complexity model, this means a change of position of BC, where it can move closer to the ordered or chaotic estate driven by a change of capability in the structure (e.g. by the addition of resources). The behaviour located beyond this boundary could be problematic and difficult to sustain because it overcomes the available PP&C system capability. Also during this process, the boundary BC has the potential to change its shape (i.e. OB ≠ OC), as the PP&C structure becomes better suited to face more stimuli with less use of resources (i.e., OB > OC). Thus, in the case of PP&C, the optimum level of behaviour arises when the boundary of the system is located in the complexity zone, while its structure closes to the edge of chaos, along with a response/stimuli relationship prone to pull behaviour.

A practical target for the behaviour model may be located within a band over the equilibrium line and around the boundary of the PP&C structure. According to Boisot and Mckelvey (2011), this behaviour in Ashby´s space involves a mixture of exploration (i.e., in the lack area) and exploitation (i.e., in the push area). The behaviour of PP&C is dynamic and evolves as the project progress, thus it seems unlikely that every single dot will be located within the boundary, instead some exploration may be needed to improve exploitation. The findings of Zegarra and Alarcón (2019) suggest a behaviour in this way.

The complexity of PP&C is both, a threat and an opportunity for improving PP&C performance. To survive a system must adapt to its environment. Thus, following Ashby´s (1957) law of requisite variety, restated by McKelvey & Boisot (2009) "... *to be efficaciously adaptive, the internal complexity of a system must match the external complexity it confronts*" (Boisot & McKelvey, 2011). During this process, managing the use of resources to answer stimuli may involve a *stimuli simplification* (i.e., using fewer resources) or a *response complexification (i.e., using more resources)*. In this way, a productive PP&C (i.e., both, effective and efficient), which properly adapts and co-evolves with the project´s requirements proper handling of complexity is critical.

Paying attention to complexity is an opportunity to improve the performance of PP&C. Interaction is responsible for the emergence of features such as variability, self-organization, and scalability, features have the potential to generate negative or positive outcomes (Boisot & McKelvey, 2011). Proper handling of interactions could be used to provide a positive impulse or to control a negative effect of these features on the system's behaviour (Choi et al., 2001)

The main limitations of this work include: The study´s scope of work focuses on the construction stage of AEC projects. The studies on which this work is based were conducted on high-rise buildings and housing construction projects which used the LPS.

CONCLUSIONS

In the AEC industry, one effective strategy used to face the poor performance of projects is to improve the PP&C system. In this context, the complexity of PP&C is a characteristic which influences the performance of this system. This concept involves three aspects: project complexity, outcomes complexity, and structural complexity. The relationship between them helps to describe the behaviour of PP&C in terms of ordered, chaotic, and complex states. Complexity represents a risk and an opportunity for the improvement and evolution of PP&C. The PP&C complexity concept suggests a route to expand the theory of Lean Project Management (based on the joint use of lean and complexity science concepts), especially to explain and guide the building of new PP&C mechanisms to face the different challenges of Construction 4.0.

REFERENCES

Ashby, R. W. (1957). *An introducton to Cybernectics* (Second; In). Chapman& Hall LTD. http://pcp.vub.ac.be//books/introCyb.pdf

Baccarini, D. (1996). The concept of project complexity - A review. *International Journal of Project Management*, *14*(4). https://doi.org/10.1016/0263-7863(95)00093-3

Ballard, G., & Howell, G. (1998). Shielding Production: Essential Step in Production Control. *Journal of Construction Engineering and Management*, *124*(1), 11–17. https://doi.org/10.1061/(ASCE)0733-9364(1998)124:1(11)

Ballard, G., & Tommelein, I. (2021). *2020 Current Process Benchmark for the Last Planner(R) System of Project Planning and Control*. https://doi.org/doi.org/10.34942/P2F593; retrieved from escholarship.org/uc/item/5t90q8q9

Boisot, M., & McKelvey, B. (2011). Complexity and organization-environment relations: revisiting Ashby's law of requisite variety'. In P. Allen, S. Maguire, & B. McKelvey (Eds.), *The SAGE Handbook of Complexity and Management* (Firsth Pub, pp. 279–298).

Sage Publications Ltd. http://philpapers.org/rec/BOICAO
Brockmann, C., & Girmscheid, G. (2007). Complexity of Megaprojects. *CIB World Building Congress*.
Burbidge, J. L. (1990). Production control: a universal conceptual framework. *Production Planning & Control*, *1*(1), 3–16. http://www.tandfonline.com/doi/abs/10.1080/09537289008919289#.VRAjMFzZ-ow
Choi, T. Y., Dooley, K. J., & Rungtusanatham, M. (2001). Supply networks and complex adaptive systems: Control versus emergence. *Journal of Operations Management*, *19*(3), 351–366.
Cristóbal, J. R. S. (2017). Complexity in Project Management. *Procedia Computer Science*, *121*, 762–766. https://doi.org/10.1016/J.PROCS.2017.11.098
Dooley, K. J., & van de Ven, A. H. (1999). Explaining Complex Organizational Dynamics. *Organization Science*, *10*(3), 358–372.
Ellis, G. F. R. (2008). On the nature of causation in complex systems. *Transactions of the Royal Society of South Africa*, *63*(1), 69–84.
Floricel, S., Michela, J. L., & Piperca, S. (2016). Complexity, uncertainty-reduction strategies, and project performance. *International Journal of Project Management*, *34*(7). https://doi.org/10.1016/j.ijproman.2015.11.007
Flyvbjerg, B. (2014). *What You Should Know About Megaprojects and Why: An Overview*. http://papers.ssrn.com/abstract=2424835
Flyvbjerg, B., Skamirs, H., Mette, K. ;, & Buhl, S. L. ; (2003). How Common and how large are cost overruns in transport infrastructucture projects? *Transport Reviews*, *23*, 71–88. https://doi.org/10.1080/01441640220000016667
Flyvbjerg, B., Skamris Holm, M. K., & Buhl, Sø. L. (2004). What Causes Cost Overrun in Transport Infrastructure Projects? *Transport Reviews*, *24*(1), 3–18. https://doi.org/10.1080/0144164032000080494a
Gidado, K. I. (1996). Project complexity: The focal point of construction production planning. *Construction Management and Economics*, *14*(3). https://doi.org/10.1080/014461996373476
Halpin, D. W., & Woodhead, R. W. (1980). *Construction Management*. John Wiley & Sons.
Hedström, P., & Ylikoski, P. (2010). Causal Mechanisms in the Social Sciences. *Annual Review of Sociology*, *36*(1), 49–67.
Jarkas, A. M. (2017). Contractors' Perspective of Construction Project Complexity: Definitions, Principles, and Relevant Contributors. *Journal of Professional Issues in Engineering Education and Practice*, *143*(4). https://doi.org/10.1061/(ASCE)EI.1943-5541.0000337
Koskela, L., Ballard, G., Howell, G., & Tommelein, I. (2002). The foundations of lean construction. *Design and Construction: Building in Value*.
LCI. (2020). *Lean Construction Instite*. Glossary. https://www.leanconstruction.org/learning/education/glossary/
Lindemann, U., Maurer, M., & Braun, T. (2009). *Structural Complexity Management*. Springer-Verlag Berlin Heidelberg. https://doi.org/10.1007/978-3-540-87889-6
Liu, M., Ballard, G., & Ibbs, W. (2011). Work Flow Variation and Labor Productivity: Case Study. *Journal of Management in Engineering*, *27*(4), 236–242.
Luo, L., He, Q., Jaselskis, E. J., & Xie, J. (2017). Construction Project Complexity: Research Trends and Implications. *Journal of Construction Engineering and Management*, *143*(7). https://doi.org/10.1061/(asce)co.1943-7862.0001306
Marks, M. A., Mathieu, J. E., & Zaccaro, S. J. (2001). A temporally based framework and taxonomy of team processes. *Academy of Management Review*, *26*(3), 356–376.
McKelvey, B., & Boisot, M. (2009). Redefining strategic foresight: "fast" and "far" sight via

complexity science. In L. A. Costanzo & R. B. MacKay (Eds.), *Handbook of Research on Straregy and Foresight* (pp. 15–47). Edward Elgar. http://www.billmckelvey.org/-0-Pubs to be added as Hot-Links--TEMP FILE/2009 McKelvey, Boisot(09)-Redefining Strategic Foresight--COSTANZO Ch 1-1.pdf

Mintzberg, H. (1978). Patterns in Strategy Formation. *Management Science*, *24*(9), 934–948.

Pereira, P., Cachadinha, N., Zegarra, O., & Alarcón, L. (2013). Bullwhip Effect in Production Control a Comparison Between Traditional Methods and LPS. *21th Annual Conference of the International Group for Lean Construction*, 619–628. http://iglc.net/Papers/Details/939

PMI. (2013). *Navigating Complexity Report | PMI Pulse of Profession*.

Schimanski, C. P., Pasetti Monizza, G., Marcher, C., & Matt, D. T. (2020). Development of a BIM-based production planning and control system for Lean Construction through advancement and integration of existing management techniques. *Frontiers of Engineering Management*. https://doi.org/10.1007/s42524-020-0105-5

Sterman, J. D. (2000). Business dynamics: Systems thinking and modeling for a complex world. In *Management*. Irwin McGraw-Hill. https://doi.org/10.1057/palgrave.jors.2601336

Taylor, T. R. B., Ford, D. N., & Lyneis, J. M. (2007). Project Controls to Minimize Cost and Schedule Overruns: A Model, Research Agenda, and Initial Results. *Social Science*, 1–27. http://www.systemdynamics.org/conferences/2007/proceed/papers/TAYLO456.pdf

Williams, T. M. (1999). The need for new paradigms for complex projects. *International Journal of Project Management*, *17*(5). https://doi.org/10.1016/S0263-7863(98)00047-7

Winograd, T., & Flores, F. (1986). *Understanding Computers and Cognition: A New Foundation for Design*. Ablex Publishing Corporation. http://books.google.cl/books/about/Understanding_Computers_and_Cognition.html?id=2sRC8vcDYNEC&pgis=1

Yin, R. K. (1994). Case Study Research: Design and Methods. In *Sage publications* (Second, Vol. 5). Sage Publications Ltd. https://books.google.com/books?id=OgyqBAAAQBAJ&pgis=1

Zegarra, O. (2021). *Study of lean and complex adaptive mechanism to regulate the function of production planning and control in construction projects* [Doctoral]. Pontificia Universidad Católica de Chile.

Zegarra, O., & Alarcón, L. F. (2015). A Production Control Tool for Coordination of Teams, Meetings and Managerial processes. *23rd Annual Conference of the International Group for Lean Construction*, *2015-Janua*, 113–122. http://iglc.net/Papers/Details/1167

Zegarra, O., & Alarcón, L. F. (2017). Variability propagation in the production planning and control mechanism of construction projects. *Production Planning & Control*, *28*(9), 707–726. https://doi.org/10.1080/09537287.2017.1304588

Zegarra, O., & Alarcón, L. F. (2019). Coordination of teams, meetings, and managerial processes in construction projects: using a lean and complex adaptive mechanism. *Production Planning and Control*, *30*(9), 736–763. https://doi.org/10.1080/09537287.2019.1578905