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WHY IS FLOW NOT FLOWING IN THE CONSTRUCTION INDUSTRY?

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ABSTRACT

The concept of flow, a core notion of lean, has been proposed and discussed throughout the construction literature for over three decades but is not yet widely applied and disseminated across industry. This paper sets out to perform an exploration of potential underlying root causes of this problem by examining a number of concepts across varied disciplines: (i) metaphysics and ontological assumptions (already discussed in the construction context), (ii) particle/wave duality (from quantum physics), (iii) co-emergence (or non-duality) (from Buddhist philosophy), and (iv) cognitive biases and fallacies (based on the work by Tversky and Kahneman). A set of six preliminary and non-exhaustive hypotheses are formulated seeking to provide insights to the problem at hand, namely, "*Why is flow not widely understood and applied in construction practice?*". Two experiment designs are proposed to test the last three hypotheses, which are related to the pragmatic aspect of this question, and thus these findings can potentially assist in a more widespread adoption of flow in practice.

KEYWORDS

Flow, theory, ontology, construction physics, metaphysics.

INTRODUCTION

A meta-analysis involving data from 24 separate studies around the world, showed that, on average, 49.6% of time on site is devoted to non-value adding activities (Horman and Kenley 2005). This means that approximately half of the time is spent on waiting, rework, excessive transportation, etc, or on supporting activities. Similar statistics were also found in Kalsaas (2010) for a highly innovative construction company, thus further demonstrating the endemic nature of the problem. Recognising that construction does not involve only direct work, but also number of other activities, is the key to improve productivity. Such an understanding has been proposed under the "flow" perspective, one of the three pillars forming the Transformation-Flow-Value (TFV) theory (Koskela 2000). Flow entails the operations dimension as well as the process dimension (namely, the passage of information, materials, etc throughout the production system). Flow introduces

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the time element to the conceptual comprehension of construction and thus by observing the production of an object over time, it becomes clear that direct work is not the only activity happening.

Seeing production through a "flow" lens is key to recognise waste and inefficiencies that are intrinsically connected to low productivity. A survey carried out with construction firms further illustrates this view (McGraw Hill Construction 2013). The results showed that 62% of lean practitioners considered construction processes to be inefficient/highly inefficient compared to 14% of non-practitioners. Complementarily, 19% of lean practitioners considered construction processes to be efficient/highly efficient compared to 55% of non-practitioners. These findings demonstrate the importance of concepts such as "flow" to be as accessible as possible to industry so that its intended benefits are realized in practice. Furthermore, Spearman and Hopp (2021) indicate that operations management has relied on axiomatic models of simplified situations or in more extreme cases ad hoc methods and heuristics. Other disciplines have a clear link to a theoretical foundation, for example mechanics in structural engineering. This research further explores the potential of flow theory in contributing to a unified science that underpins construction management.

This paper examines the following question: "*Why is flow not widely understood and disseminated in construction practice*?". Conceptualizations from different domains including (i) metaphysics and ontological assumptions, (ii) particle/wave duality (from quantum physics), (iii) co-emergence (or non-duality) (from Buddhist philosophy), and (iv) cognitive biases and fallacies (based on the work by Tversky and Kahneman) are reviewed. Hypotheses are then formulated based on the revised notions and two experiment designs are outlined to test three of these hypotheses. This manuscript is exploratory in nature. It aligns with the concept of the "ripple effect" (namely, that science should create more questions than answers) discussed in the TED talk "The Pursuit of Ignorance"[4] by Stuart Firestein. Accordingly, the paper seeks to introduce a non-exhaustive number of angles that can help to explain the lack of understanding and dissemination of the flow concept in practice despite being proposed for thirty years[5] now. The importance and need for such type of in depth theoretical studies to advance knowledge has been highlighted in both operations (e.g Spearman and Hopp 2021) and construction management (e.g. Howell and Koskela 2000; Koskela et al. 2019; Seymour 1996) disciplines.

LITERATURE REVIEW

FLOW IN CONSTRUCTION

One of the early understandings of flow in construction was proposed by Koskela (2000) who presents a three-type flow model comprised of (i) material or supply chain (e.g. a window production and transportation until installation on site), (ii) location or space (e.g. a team moves through the building installing windows), and (iii) assembly or previous work (e.g. the building progresses through all construction or assembly stages). Bertelsen et al. (2006, 2007) contend that construction entails a myriad of flows (e.g. information, space, crews, etc.) that are interconnected serving a number of different projects at the same time. For example, the flow of procurement feeds the flows of materials, equipment and workers. As there is not only a single flow but rather several flows, the flow

[4] https://www.ted.com/talks/stuart_firestein_the_pursuit_of_ignorance

[5] Considering the formal introduction of "flow" in the construction literature context by Koskela (1992)

controlling the progress of a project (termed as critical flow) is constantly changing rendering the task of identifying and managing such a flow challenging, if at all possible (Bertelsen et al. 2007).

In a more recent study, Sacks (2016) presents a conceptual framework for good flow in production. The paper proposes two types of flows based on Shingo and Dillon (1989): (i) process flow (progress of a product along workstations or in the construction context the progress of teams completing construction tasks in different locations of a building) and (ii) operations flow (actions performed on the product or the building by a workstation or a team). Interestingly, a "task" (elementary and not a flow) in Koskela (2000), exemplified by a team installing one window, is converted into operations flow in Sacks (2016) as from a team's perspective that task is repeated over time in different locations. This latter notion can be expanded to different locations within a building but also across buildings, which is captured under the "portfolio" notion of different projects being built at the same time and a team flowing across all of them (Sacks 2016).

METAPHYSICS AND ONTOLOGICAL ASSUMPTIONS

The distinction between two basic world views, namely, (i) substance metaphysics (e.g. concrete, bricks, etc) and (ii) process metaphysics (e.g. heat, light, etc) dates from the pre-Socratic period of philosophy (Koskela and Kagioglou 2005). The referred authors state that construction is inherently a process-oriented endeavour, yet a majority of research and practice in this field measures the effectiveness of the process purely from the outcome or through a substance-oriented view. This results in problems such as the excessive focus on productivity as a measure and explanation of the efficiency in construction and the assumption that plans are deterministic rather probabilistic (Koskela and Kagioglou 2005). Transformation (as part of TFV) captures the substance-view by understanding construction to be a series of independent sub-transformations. On the other hand, Flow (also as part of TFV) embodies the process-view by conceptualising construction as the flow of material in space towards an output (Koskela and Kagioglou 2005). A different angle is introduced by Koskela et al. (2007) in proposing that TFV could be viewed from a substance (TFV^t) or a process (TFV^p) metaphysics.

Nonetheless, the disconnection between the ontological categories of "substance" and "process" is an acute barrier to understanding process phenomena (Rooke et al. 2007). The referred authors carried out two ethnographic studies (on structural design and quantity surveying) to explore the methods of reasoning, which are focused on objects rather than processes as the core elements for understanding construction projects. In the first study, it was observed that the explicit elements considered in pricing are the physical parts forming a building (concrete, its types, quantities, etc). On the other hand, task related costs (transport and placing of concrete, etc) were viewed as ancillary properties of the physical parts (Rooke et al. 2007). The second study highlighted the view of (i) design and (ii) implementation of design (construction process) as two independent entities rather than interconnected and iterative phases demonstrating an excessive emphasis on design in comparison to the implementation of design. This overlooks variability in size, shape, dimensions, whenever an object is translated from the idea domain (design) to the physical domain (actual constructed product), resulting in technical (quality, defects) and contractual problems.

The overarching dominance of a matter or substance-view in understanding phenomena and the world around us has also been observed in other fields, which might suggest that the process-view has challenges. Chi et al. (1994) discuss a recurring misconception of scientific conceptualisations belonging to the process ontological category such as light, electrical current, etc, to be placed in the thing (or matter) category. According to Chi et al. (1994), the confusion might stem from the fact that process entities involve components from things categories (such as wires, batteries, particles, etc in the case of the electrical current). But the involvement of these components does not mean that the electrical current remains in this category, nor is a property of the components (Chi et al. 1994). Therefore, the natural preference towards the conceptualisation of entities as matter (or things) may be due to the familiarity with concepts in this ontological category. The referred authors do not expand further on this idea, but it is proposed here that human beings perceive (via our senses and mind) the world as solid and atemporal to a large extent, and because of such first-hand experience we tend to frame most phenomena based on this ontological category.

CO-EMERGENCE

The Buddhist *koan* ("what is the sound of one hand clapping?") provides another angle to tackle the issue discussed in the previous section. The idea is that a hand does not have an inherent sound per se, namely, the sound will depend on the object with which the hand engages. If it is another hand, the sound would be of what we traditionally think of hands clapping, but if we clap our hand against a wooden desk or a glass window, we will have different sounds, meaning that the sound of a clap is a property that emerges from the interaction of two entities (the hand and the other chosen object), thus resulting in the term "co-emergence". Thus, matter entities are an intrinsic part of process entities: namely, sound only exists via the interaction of two objects. As a result, positioning the matter view (T view) in opposition or perhaps as a lesser view in comparison to the process view (F view) can suggest that these are independent and/or that the F view should be preferred. In fact, T and F tackle the same entities, namely, construction activities, yet the former has a microscopic focus (the individual activities as independent entities) whereas the latter has a macroscopic focus (the system formed by a set of activities and the features that emerge from such a system). Thus, similar to the *koan*, a hand (or activity) exists as an individual entity (T view), yet the co-emergence (or system features) only arises when two or more entities are combined (F view). In the case of a hand, this leads to different sounds. From a construction process perspective, it leads to less or more waste, efficiencies, etc, depending on the system delivering such activities.

PARTICLE/WAVE DUALITY

Overall, the matter and process views of the world seem to be presented in opposition, namely, an entity will either belong to one category or the other, or at best their interrelated nature is only marginally discussed (as in Chi et al. 1994). It is proposed here that this dual or binary rationale further hinders the understanding of the process-phenomenon: if something is not a physical part (as in matter entities), then what is it? And how can we perceive it? In that sense, the sound of one clap koan previously discussed and the double slit experiment and the particle/wave duality (from quantum physics) can shed some light. The latter demonstrates that at an atomic scale, light when going through a double slit assumes a particle behaviour and hits the screen as a particle but ultimately creates a wave pattern. This means that at such scale, light cannot be strictly classified as matter (particle) or a process (wave), thus creating a Particle/Wave duality. This prompts us to revise the binary perspective in which we usually operate in ("this OR that") and the possibility of a more open perspective ("this AND that").

COGNITIVE BIASES

Following on the rationale and notions presented in the previous sections, the first problem to consider is whether or not people are able to perceive the construction phenomenon from a process perspective. If the answer is yes, a second problem is whether (or not) they have an intuitive understanding of the fundamental properties of statistical distributions such as standard deviation, variability, queuing theory, etc. For example, this type of investigation would question whether a site engineer can interpret task duration distribution data to define an appropriate schedule. Furthermore, if the site engineer is able to understand the statistical distribution, it is key to measure the influence of risk attitudes and behavioral perceptions associated within the interpretation and the subsequent decision making. From a practical viewpoint, the second problem is as critical as the first one, as it will ultimately impact people's ability to make appropriate decisions and consequently obtain the benefits (reduced waste and inefficiencies). Comprehension and understanding of the flow perspective can potentially improve this aspect of the construction domain. This is in line with Spearman and Hopp (2021) who argue that the lack of a descriptive science for operations has resulted in a lack of intuition about the basic concepts (e.g. cycle time and WIP) among professionals in practice.

Research carried out by Tversky and Kahneman have also demonstrated people's bias and misconceptions of even basic statistical and probability notions. These have been observed in a number of professional areas such DNA testing, court trials, and medical prognosis, leading to poor decision making and affecting outcomes. One case is the conjunction fallacy (Tversky and Kahneman 1983), which explains that people tend to overestimate the likelihood of two events occurring in conjunction relative to each event occurring independently. In one of the studies by Tversky and Kahneman (1983), participants had to select the most likely statement (from a set of five options) based on the description of a fictional individual (Bill). A statement with two attributes (Bill is an accountant who plays jazz for a hobby) were selected as more likely than statement with a single attribute (Bill plays jazz for a hobby) (Tversky and Kahneman 1983). In a variation of such fallacy, the participants had to choose the combination for 20 successive rolls of a dice with four red faces (R) and two green faces (G) from three options: (i) RGRRR, (ii) GRGRRR, and (iii) GRRRRR. 62% of participants chose the second option as it appeared to be more representative of a random sequence despite the fact that the first option is contained within the second option and more likely to occur (Tversky and Kahneman 1983).

WHY IS FLOW NOT WIDELY UNDERSTOOD AND USED?

Based on the conceptualizations presented in the previous sections, six exploratory non-exhaustive hypotheses are proposed for unveiling root causes contributing to the limited understanding and adoption of flow in construction practice.

- H1. Flow is tricky to grasp (due to its inherent non-dual and co-emergent nature) and the difficulties observed in construction are no different than the ones detected for similar concepts in other fields (physics education, etc).
- H2. The dichotomy of matter and process views ("this OR that"), and the negative connotation of the former, hinders the understanding of the latter by introducing the misconception that the process entities entail elements other than the one found in the matter domain.

- H3. Flow and its more tangible manifestation (queues) as observed in other contexts (manufacturing of products, vehicles in traffic, etc.) enable such a concept to be more easily perceived.
- H4. The specific features of construction (production happens inside the product, immovable product, etc.) hide these more tangible manifestations, making flow invisible in this context.
- H5. Due to the invisibility of flow, cognitive biases related to statistical thinking are more prevailing in construction than in flow visible environment (manufacturing of products, vehicles in traffic, etc.).
- H6. Differently from manufacturing, time instead of inventory is used to mitigate flow variability and the former is less measurable/visual/tangible and more transient than the latter.

H1 and H2 are stimulating from a theoretical viewpoint, yet have limited contribution from a practical angle, namely, in enhancing the understanding of flow in construction practice and consequently in its widespread adoption and dissemination. The effect of moving workstations and a static product (instead of the other way around as in manufacturing) have been explored in Bølviken and Koskela (2016) in a similar vein to H4 and H6 but focused on waste. According to Bølviken and Koskela (2016), waste is constantly changing and thus not necessarily observable over time. For example, a worker is waiting for a drawing for two hours, but such waste disappears as soon as he receives them. In addition, waste has a dispersed nature due to work/activities being performed by distinct crews in different locations often hidden from each other due to structural and enclosed systems, thus further adding to its unobservable (or invisible) nature. The remainder of this paper focuses on the exploratory design of two experiments (under development by the authors of this manuscript) for corroborating or refuting H3, H4, and H5 hypotheses.

DESIGN OF EXPERIMENTS

INVISIBILITY OF FLOW IN CONSTRUCTION

Table 1 summarizes the experiment design structure for H3 and H4, which is comprised by a number of questions and by four simulation scenarios based on Figures 1 and 2. Options A and B (detailed in Table 1) would both show a production line (Figure 1), respectively, with a one piece even flow (thus no queues or WIP) and with an uneven flow (thus creating WIP between the stations). The same logic would apply for options C and D (also detailed in Table 1) but instead of products, trades would move across the different rooms of the building (Figure 2). The experiment has the same structure for the first and third blocks (Table 1) which seeks to identify if people are able to perceive flow and queues in these two contexts. This is followed by a decision-making question to identify if they are able to recognise the negative effect of queues. The second block aims to identify if participants can recognize such phenomena in construction prior to seeing the simulations developed for this context.

Figure 1: Sketch for manufacturing simulation

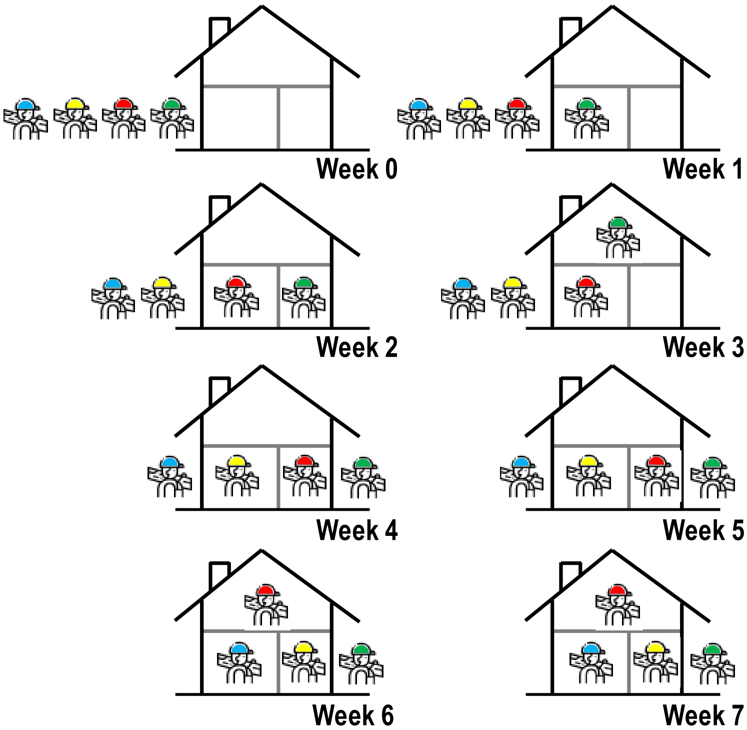

Figure 2: Sketch for construction simulation

Table 1: Experiment structure

Dynamics	Aim	Questions
Option A is shown (Figure 1 with an even and continuous flow of products) and questions 1 and 2. Same is repeated for Option B (Figure 2 with an uneven flow of products). Question 3 is asked.	Block 1 - Perception of flow and queues in manufacturing	1. Is there a flow? ( ) No ( ) Yes. Please describe it. 2. Is there a flow? ( ) No ( ) Yes. Please describe it. 3. If you are the factory manager, would you prefer option A or B? Why?
No image/simulation	Block 2 - Beforehand understanding of flow and queues in construction	4. Do "flow" and "queues" apply to construction? ( ) No ( ) Yes, for "flow" and "queues". Please describe: What would be a "flow" in construction? What would be a "queue" in construction? ( ) Yes, for "flow" only. Please describe: What would be a "flow" in construction? ( ) Yes, for "queues" only. Please describe: What would be a "queue" in construction?
Option C is shown (Figure 2 with an even and continuous flow of trades) and questions 5 and 6 are asked. Same is repeated for Option D (Figure 2 with an uneven flow of products). Question 7 is asked.	Block 3 - Understanding of flow and queues in construction after analogy with manufacturing/ queues are made visible	5. Is there a flow? ( ) No ( ) Yes. Please describe it. 6. Is there a queue? ( ) No ( ) Yes. Please describe it. 7. If you are the site engineer, would you prefer option C or D? Why?

INCORPORATION OF COGNITIVE BIAS

A series of scenarios with four sequential construction activities (wall, flooring, windows installation, and painting) completed by two contractors (Tables 2 and 5) for a hypothetical high-rise building are proposed to test H5. Participants would be asked to select the preferred option: (i) *Contractor A*, (ii) *Contractor B*, and (iii) *Does not matter as both contractors will complete the building at the same time*. These scenarios and the answer provided can assess the understanding of underlying statistical assumptions (e.g. presence or absence of variability, effect of increasing levels of variability, etc) as shown in the captions for Tables 2 to 5. A "why" follow up question (after the closed ended ones) provides further insights on participants' reasoning and rationale for the preferred option in each of the Scenarios.

Another experiment design related to cognitive biases in statistics can be also derived from the seven pre-conditions for task completion (Koskela 2000). Considering that the probability of each pre-condition being met is 0.95, the probability of completing the task, namely, having all six conditions met is only 0.70, resulting from 0.95^7 (Koskela 2000). This example presented in Koskela (2000) structured as an experiment has the potential to assess the misconception that the probability would be 0.95 (probability for each prerequisite condition) instead of the 0.70 (correct answer). Such bias is in line with previous ones such as the conjunction fallacy identified by Tversky and Kahneman (1983) in which people wrongly consider the likelihood of two events occurring in conjunction to be bigger than the likelihood of each event happening independently.

Table 2: Presence or absence of variability (Scenario 1)

	Contractor A	Contractor B
Walls	1 floor every 3 or 5 weeks	1 floor every 4 weeks
Flooring	1 floor every 3 or 5 weeks	1 floor every 4 weeks
Windows installation	1 floor every 3 or 5 weeks	1 floor every 4 weeks
Painting	1 floor every 3 or 5 weeks	1 floor every 4 weeks

Table 3: Effect of increasing levels of variability (Scenario 2)

	Contractor A	Contractor B
Walls	1 floor every 3 or 5 weeks	1 floor every 2 or 6 weeks
Flooring	1 floor every 3 or 5 weeks	1 floor every 2 or 6 weeks
Windows	1 floor every 3 or 5 weeks	1 floor every 2 or 6 weeks
Painting	1 floor every 3 or 5 weeks	1 floor every 2 or 6 weeks

Table 4: Effect of higher productivity upstream (Scenario 3)

	Contractor A	Contractor B
Walls	1 floor every 2 weeks	1 floor every 4 weeks
Flooring	1 floor every 2 weeks	1 floor every 4 weeks
Windows	1 floor every 4 weeks	1 floor every 4 weeks
Painting	1 floor every 4 weeks	1 floor every 4 weeks

Table 5: Effect of higher productivity downstream (Scenario 4)

	Contractor A	Contractor B
Walls	1 floor every 4 weeks	1 floor every 4 weeks
Flooring	1 floor every 4 weeks	1 floor every 4 weeks
Windows	1 floor every 2 weeks	1 floor every 4 weeks
Painting	1 floor every 2 weeks	1 floor every 4 weeks

The experiments discussed here are intended to explore a decision makers' comprehension of flow within the construction management domain. Though risk attributes and perceptions could be estimated by correlating and modelling demographic parameters of participants against the choices made in the second experiment (Wijayaratna and Dixit 2016), these fail to capture game theoretic scenarios that can occur (Kapliński and Tamošaitienė 2010). For example, "prisoners' dilemma" scenarios where individuals have an incentive to make decisions that are favorable for the individual but do not advantage the group/team objective are scenarios that need to be explored further in the context of flow. In addition, lack of incorporation of perfect and imperfect information is also a limitation of the experiments that are being designed. However, the experiments can provide valuable insights into comprehension of flow and the influence of statistical bias, which can lead to better educational tools built on the theoretical foundation of lean principles.

CONCLUSIONS

This paper presented a conceptual exploration on flow and why this concept is not yet flowing in construction practice. It started with the review of conceptualizations from different disciplines followed by a discussion of their connections with the construction context to understand and tackle the root causes of such a problem. The outcomes of the exploratory exercise were six non-exhaustive hypotheses that seek to answer the following question: *Why is flow not widely understood and disseminated in construction practice*? The lack of theory in flow (regardless if this entails more or less complicated conceptualizations) is likely to contribute to the problem. Koskela et al. (2019) has highlighted the emphasis (especially in the West) on developing practical methods and tools in education and training instead of investing in the clarification and establishment of fundamental theories. This can be an underlying reason for the lack of understanding of lean, including its application in construction. This resonates with Spearman and Hopp (2021), who criticise operations management for relying on simplified axiomatic models and/or ad hoc methods and heuristics, thus lacking a coherent science for how systems behave. Likewise, the emphasis on tasks (by the widespread use of CPM tools) as well as the matter view in costing and design areas (as reported in Rooke et al. 2007) further adds to the problem.

The first two hypotheses are not context specific and simply position that human beings would have an inherent difficulty (or perhaps a physiological impairment) in perceiving the world through a process-view, consequently meaning that flow and other process phenomena are intrinsically difficult to grasp. These hypotheses seem to be supported by research in other fields such as (Chi et al. 1994), yet a more systematic and comprehensive analysis of other disciplines needs to be carried out for more robust conclusions to be drawn. Another interesting avenue would be to examine the human perception process and cognition mechanisms. This can help uncover if the approach of separating a system into sub-components and to manage each sub-component individually (aligned with the matter or T view) is innate or wired in human brains to enable us to process and make sense of all the stimulus of the world surrounding us. The other hypotheses are context specific and assume that construction (further) hinders the comprehension of flow. To some extent, this second set of hypotheses is independent from the first one. H1 and H2 can be corroborated, but if flow in this setting is indeed invisible (or less visible than in other contexts), an additional hindrance in its realization applies.

Different from H1 and H2, which would rely on literature review, two experiments are proposed for the testing the other hypotheses: three blocks of questions (Table 1 and Figures 1 and 2) for H3 and H4 and a multiple choice repeated questionnaire for four different scenarios (Tables 2 to 5) for H5. The second experiment is in line and inspired by the work carried out by Tversky and Kahneman, and thus can be viewed as an extension of the exploration of cognitive biases related to statistical thinking carried out by the referred authors to the construction context. The first experiment on the other hand was designed to evaluate a new notion proposed here: the invisibility (or not) of flow and the impact of the specific features of construction in that regard. The next step of this research will entail the pilot testing and refinement of the two experiments followed by a large-scale data collection with industry practitioners to enable a statistical analysis to be performed. The open-ended questions will help understand the black box of such quantitative results, providing insights into the "why" and "how" behind the reasoning around flow in construction practice.

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