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LEAN CONTRIBUTIONS TO BIM PROCESSES: THE CASE OF CLASH MANAGEMENT IN HIGHWAYS DESIGN

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ABSTRACT

Managing design is still considered a challenge and few design and construction companies apply Lean and BIM in an integrated manner to support it. The interactions of Lean and BIM have been explored for more than 10 years. Despite this, most of the practical and theoretical discussions have focused on BIM capabilities' and features' contributions to Lean goals and techniques. Therefore, this paper aims to explore and discuss Lean contributions to BIM processes, which is still missing in the analysed context. Initial findings of an ongoing research project on exploring Lean and BIM synergies in the UK are presented. The investigation adopts case study as its research strategy, while exploring the potential implementation of Lean into the BIM-based clash management in highways design. The paper contributes to knowledge by determining how Lean could reduce waste and increase value of a clash detection and resolution process. The results indicate that Lean can contribute to the BIM processes, beyond the BIM capabilities and features, to support BIM process improvements. The wide range of intervention opportunities in BIM processes from a Lean perspective needs further investigation for Lean to have a firmer place in BIM discussions.

KEYWORDS

Lean and BIM, clash management, process, design management, waste.

INTRODUCTION

Lean production is a managerial philosophy, i.e. a combination of principles, tools and techniques, that emerged in the manufacturing sector and has been applied and adapted to construction since the 90s. It has been pointed out as an important approach to increase stakeholders' value, as well as to eliminate activities that do not add value (Womack et

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al. 1991); sharing the same principles with Lean construction, which is the reflection of Lean production on the construction industry. On the other hand, Building Information Modeling (BIM) is described as a process to design, construction and facilitity management, which can involve all project stakeholders (Hamdi and Leite 2012). Being the digital replica of a built asset, it is becoming a key product and process to support information management in project management in order to improve the project life cycle.

The literature has pointed out numerous synergies between BIM and Lean since 2010, enabling the industry to focus on the life cycle value (Dave et al. 2013; Sacks et al. 2010; Tzortzopoulos et al. 2020), even though they emerged as separate initiatives. According to Dave et al. (2013), there are four major mechanisms for how Lean and BIM interact: (i) BIM contributes to Lean goals, (ii) BIM enables Lean processes, (iii) auxiliary information systems, enabled by BIM, contribute to Lean, and (iv) Lean processes facilitate the introduction of BIM. However, investigations mostly focus on BIM's and auxiliary information systems' contributions to Lean techniques, and goals, which have been widely recognised in the literature and practice. For the design phase, the main focus of the current discussions is on how to solve specific design problems through the use of BIM based tools, such as clash detection, and how to facilitate the realisation of some Lean goals (Tzortzopoulos et al. 2020), not giving due regard to how Lean can contribute to BIM processes.

This paper reports findings of an ongoing Knowledge Transfer Partnership (KTP) with an infrastructure design and consultancy company, aiming to explore the integration of Lean and BIM. The aim of the paper is to investigate Lean contributions to BIM processes, over an illustrating case about clash management in highways design. BIM-related processes are still fragmented and wasteful, characterising the practical justification of the research, thus Lean can offer solutions. However, there are not enough investigations on Lean's contributions to BIM processes in the literature and practice, and this needs to be expanded. The synergetic interactions between Lean and BIM have been observed to exist, but at the moment, the highways sector does not seem to utilise them much, and in any case not in a systematic manner. Software issues have in the past prevented the adoption of Lean techniques for clash detection in Highways, an issue that does not exist in other disciplines such as Buildings. Also, related research has mostly focused on building projects, and it is not known whether the interactions would be the same in highway projects.

SYNERGIES OF LEAN AND BIM

The impacts of Lean and BIM are deep on their own when considering their separate applications; however, in addition to their parallel development, they also have synergistic impacts when implemented in integration (Sacks et al. 2010). Sacks et al. (2010) identified 52 positive interactions out of total 56 interactions between Lean and BIM. Significant positive interactions include: (i) reduction in design and construction work variability; (ii) reduction in design and construction cycle-times; and (iii) improved information flows and stakeholder engagement through visualisation of the product and process. By identifying those synergies, Sacks at al (2010) and Hamdi and Leite (2012) argue that the full potential of BIM and Lean can only be achieved through integrated approaches.

From the BIM to Lean aspect, it is important to highlight the opportunity and the need for information technologies to support Lean production management workflows (Tzortzopoulos et al. 2020), e.g. focusing on computer-assisted optimisation of process

(Schimanski et al. 2019). The use of BIM allows certain activities, which do not add value to the product and the process, to be automated or eliminated (Tezel and Aziz 2017).

The use of BIM as a way to enable effective Lean practices has been massively documented; however, the use of Lean for achieving improved levels of BIM adoption and processes has not been adequately explored (Mahalingam et al. 2015). This perspective outlines how Lean can support the implementation and continuous improvement of BIM. Practices such as colocation of stakeholders or implementation of big rooms for collaborative discussions and visualisation have been suggested as approaches to support BIM implementation through an improved coordination (Dave et al. 2013; Eastman et al. 2008).

Moreover, Lean has a potential to improve BIM processes and the literature has revealed new implementation opportunities in that regard. Uusitalo et al (2019) and Bhatla and Leite (2012) highlighted a lack of clarity on how to connect the different BIM concepts, e.g. level of detail, with Lean tools, such as the Last Planner® System (LPS), in order to develop correct and useful models. The use of the LPS as a BIM enabler has been also investigated by Mahalingam et al. (2015), who argue that more work can be developed in order to understand how other Lean tools can improve the information transfer within BIM-based projects. Process map and value stream analysis can impact the transparency of the processes (Klotz et al. 2008), and can also benefit BIM process improvements. BIM not only enables Lean goals, but it can also be enabled by Lean adoptions, such as collaboration and continuous improvement.

CLASH MANAGEMENT

Akponeware and Adamu (2017) highlighted that the detection of clashes has fascinated researchers for decades; however, the phase and time to detect a clash have progressively changed from a reactive activity, i.e. on-site activity, to a proactive activity in the preconstruction design phase. The clash detection or interference checking process refers to the practice of identifying clashes in a federated BIM model, which can be defined as waste in the production system (Tommelein and Gholami 2012). It is one of the many quality checks conducted by the design team before they release the product (Chahrour et al. 2021), and it is a "necessary non-value adding activity". Design conflicts must be made visible, characterised, and have root causes identified, as a way to improve efficiencies and reduce wastes (Tommelein and Gholami 2012). Nevertheless, clash detection tools still generate huge amounts of irrelevant conflicts, which require time and resources to solve (Hartmann 2010).

The clash detection and resolution process involves identifying the conflicts in a 3D BIM environment, which is obtained by performing pair-wise comparison checks between a set of elements or disciplines (Radke et al. 2009). According to the ISO 19650-1 (2018), issues can be spatial, e.g. elements and services in the same space, or functional, e.g. materials not compatible with the regulations. Spatial clashes can be classified as "hard", two objects are in the same space, "soft", one object overlaps the operating or maintenance space of another object, or "time", two objects are in the same place at the same time.

Coordination and clash detection improvements are included in the key reasons for BIM implementations (Akponeware and Adamu 2017); however, there are few investigations in clash management, apparently due to the mistaken idea that it is a simple and automated process. Few studies explored clash detection considering the process and investigating the root causes of clashes in building information models. Chahrour et al.

(2021) proposed a clash categorisation, considering the change impact and dependency on the stakeholders involved. Tommelein and Gholami (2012) identified the causes for hard and soft clashes, e.g. failing of design rules and design error. Thus, there is still a gap in the formalisation of the clash detection and resolution process, as most investigations focus on software tools instead of the process elements i.e. activity flows, required resources and underlying purposes, to support coordination.

RESEARCH METHOD

The paper presents the initial findings of an ongoing research project through a case study. The case study research method is typically chosen when the (i) type of research question posed is why and how, (ii) the investigator has no control over events, and (iii) there is a high degree of focus on contemporary events (Yin 2003). An empirical case study was carried out with an infrastructure design and consultancy company (company A) based in the UK. This investigation consisted of a critical analysis of the BIM processes at the company from a Lean perspective, aiming to understand how Lean principles and tools can be adopted to enable BIM use. Company A operates in the highways design and construction sector. The company was selected due to their willingness to participate in this research project, and also because it had previously adopted Lean and BIM practices to support design development and management. However, the Lean and BIM integrated implementation within the company was fragmented, lacked co-ordination and was still immature.

The scope of the analysis is restricted to one of highway design project, and thus the generalisability of the conclusions is limited. However, the clash detection and resolution process analysed in this paper was similar to the processes adopted in other projects within the company. The study was conducted in three stages: (i) understanding of the problem and the company’s design processes, (ii) development and analysis of the clash detection and resolution process map in collaboration with company stakeholders, and (iii) analysis and reflection on the Lean contributions to the BIM processes. The main sources of evidence were: (i) workshops to refine the highways alignment and to develop the clash detection and resolution process in collaboration with the design and BIM leads (i.e. BIM managers and coordinators), and (ii) analysis of the existing design coordination documents (e.g. clash analysis report, clash resolution action plan, and lessons learned document), and existing process maps (e.g. overall and discipline-specific processes map). The workshops also enabled the discussions regarding improvement opportunities, whilst the document analysis supported the examination and evaluation of the current state and triggered suggestions for future state.

CASE STUDY ON CLASH MANAGEMENT - COMPANY A

DESCRIPTION OF THE CURRENT STATE

The starting point of this investigation was the understanding of the company’s design process through three different levels of analysis: (i) overall process map of key design disciplines (level 1), (ii) discipline-specific processes connecting the stakeholders involved, i.e. highways alignment (level 2), and (iii) BIM sub-processes, detailing a process that required more attention, i.e. clash detection and resolution (level 3). Figure 1 shows the complexity associated with the design process and subprocesses. The highways discipline-specific process (level 2) was refined from previous developments and the clash detection and resolution process (level 3) was developed in the framework of this research through the workshops, not existing prior to this study.

The development of a specific highways scheme, which was part of a wider programme of schemes to improve connections in the UK, was used to conduct the clash management investigation through a retrospective analysis with the company staff. The clash management information was simplified for this paper, due to data confidentiality. In this work, clash management, i.e. detection and resolution, is described as an interactive process between the design and the BIM team in order to identify, classify, and resolve conflicts to achieve a minimum number of clashes. Navisworks was one of the main tools used to detect the clashes. A clash was defined by the company as spatial (hard and soft) or functional, following the ISO 19650 (2018) definitions.

The discussions with the company employees through the workshops showed that the teams carried out the clash management through an informal process, with no clear definition of responsibilities and sequence of activities. The key clash detection and resolution activities identified through workshops and document analysis are described as (Figure 1 – Level 3): (1) define and communicate the federation strategy, (2) generate models and prepare the disciplines for federation, (3) prepare the federated model and federate the discipline models, (4) perform clash detection on the federated model, (5) report the clashes and analyse issues detected, (6) publish the federated model, (7) organise and undertake regular design coordination meetings, (8) resolve issues detected by the clash detection, update and share the updated models, (9) update the clash register and issue a report (if required). Activities 2 and 8 were carried out by the design team, whereas the others were mostly related to the BIM team or in the interface between those stakeholders. The project analysis ran about 20 clash detection cycles.

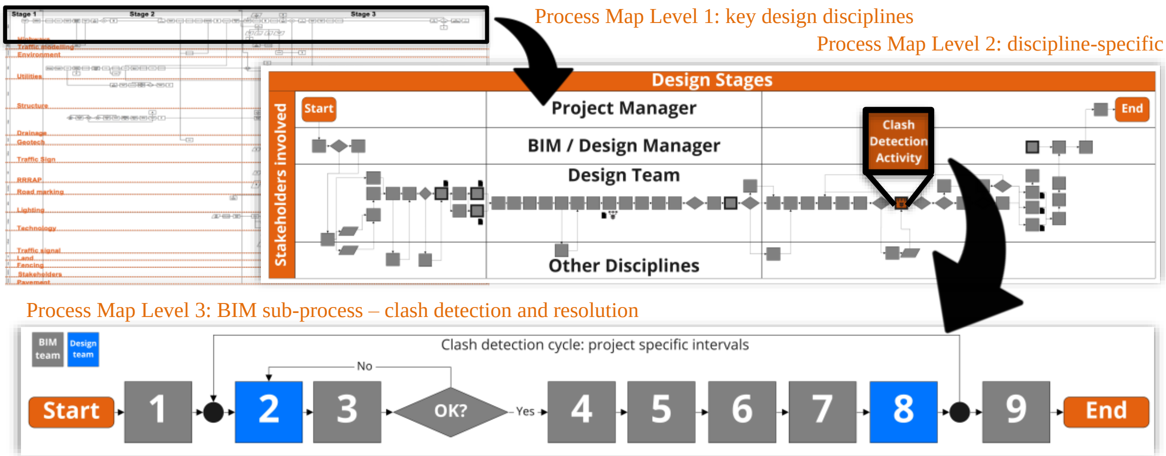

Figure 1: Company design process with different levels. The numbers in the boxes of the Process Map Level 3 refer to the clash detection and resolution activities carried out by the BIM (grey) and design (blue) teams.

The company adopted a silo-based approach to develop the discipline models before any federated model was created and any coordination was performed. The software used to undertake the design was also relatively new, also contributing to a huge inventory of clashes at the beginning of the clash detection process in the detail design stage. Approximately 8500 clashes were detected at the beginning of the process (Figure 2 shows the evolution of the number of clashes in the detail design stage). This approach has similar characteristics as the process of conflict identification in the pre-BIM era, in which drawings (digital or not) were manually compared to each other through an overlap of discipline drawings.

A clear target had been set by the client to achieve a fully clash-resolved BIM model before the submission of target price for the construction works. It resulted in the implementation of a multi-disciplinary management process for the BIM clash resolution. Key conflicts were discussed and resolved during coordination meetings, where the clashes identified in the federated model were displayed on a screen and the visualisation supported the discussion. A clash resolution action plan was also used to support the design coordination meetings (Figure 3). However, an effective record of clash occurrence was rarely developed, making it difficult to learn from the previous experience. Clash resolution action plans were reviewed and updated on a weekly or fortnightly basis and reported back to the client.

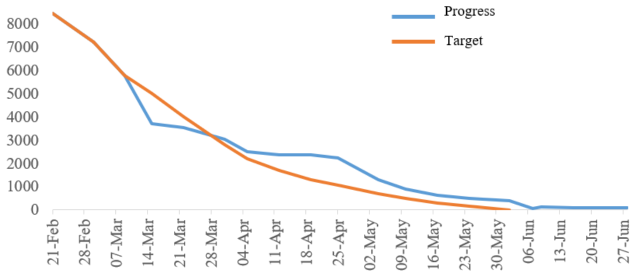

Figure 2: Evolution of the number of clashes.

Weekly or Fortnightly Cycle of Clash Detection (1 - n)												
Date:												
Prerequisites (discipline vs discipline)	Clash status							Clash Owner	Underlying Issue	Actions (current week)	Actions (next week)
	Sum of total	Sum of new	Sum of active	Sum of reviewed	Sum of approved	Sum of resolved (Closed)	Sum of Unresolved (Open)				

Figure 3: Clash resolution action plan.

ANALYSIS AND EVALUATION OF THE CURRENT STATE

The clash management activities were considered by the company as necessary non-value adding activities to coordinate all disciplines and to eliminate model conflicts, or even waste in the design process, especially when the activities relied on manual and time-consuming activities. There is no robust recording of efforts spent on the clash detection and resolution process. Approximately 27 BIM and design team members were involved in the process, including the clash owners (design leads), designers, BIM manager and coordinator, and design manager. However, the company staff pointed out that the workload related to BIM works had been underestimated due to lack of previous experience, and the resource requirement was significantly higher than the estimated.

The use of a federated BIM model enabled effective decision-making to solve conflicts with less rework, mostly due to the ability to visualise a consolidated model. Thus, the BIM process enabled collaborative decision-making among a multi-disciplinary design team. There was also an early involvement of the contractor in the process, including their support in the definition of the construction tolerances for clash detection. The high number of clashes required very close management to gain the client's confidence.

The key root causes for the inventory identified by the BIM leads were associated with (i) expected or intentional clashes, which can be resolved on site with minimal impact (allowable clashes that will support the construction stage) and can be related to the way the design was modelled (type I), (ii) design modelling errors which should be removed prior to construction stage, also related to the way it was modelled and the level of detail required (type II), (iii) minor errors of coordination between different disciplines (type III), and (iv) similar clashes that had not been grouped according to the disciplines at the beginning of the process (type IV). Due to the urgency associated with the design process, no root causes were analysed through a structured approach, even if the company has adopted a clash resolution action plan (Table 1). As a consequence, no actions were taken to prevent issues from recurring through a lessons learned exercise.

A clash-free federated model was required by the client contractually; however, it was labelled by the BIM leads as "unachievable". Construction tolerances were agreed with the construction company, considering 25% of the clashes were deliberately transferred to the construction company in order to communicate and raise awareness about specific conflicts (clash type I), e.g. safety barrier foundations and utilities were intentionally clashed, as a result of the way they were modelled, to inform the contractor of the location and to avoid placing the posts. The high number of clashes did not provide a realistic picture of the design maturity, so instead of reporting the number of clashes in BIM, the team could have reported the number of issues in BIM (e.g., resolving one issue could resolve hundreds of clashes), focusing on the design process and reducing the reliance on software. Also, due to technical issues, there was a need to repeatedly re-approve previously approved clashes following model updates.

SUGGESTIONS FOR THE FUTURE STATE

The clash detection and resolution activities should be performed systematically to maintain the accuracy of information and automate the activities that do not add value. It is fundamental that the company stakeholders understand where process inefficiencies are, so they are able to measure the value of BIM and Lean improvements. The formalisation through the process mapping exercise and analysis of the current process highlighted opportunities for improvements. Identifying improvements has enabled the company stakeholders to be conscious that even a simple activity, such as the definition of the federation strategy, and clash analysis and report, will require protocols for data structuring. The key activities of a clash detection and resolution process and identified improvement opportunities are presented in Figure 4 and Table 1.

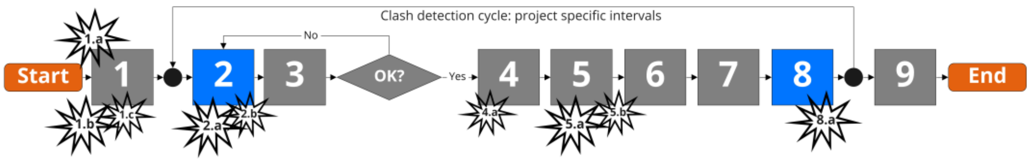

Figure 4: Improvement opportunities identified. The explosions represent the improvement opportunities and are further described in Table 1(second column). The numbers in the blue and grey boxes refer to the same activities as described in Figure 1 and Table 1 (first column).

The improvement opportunities were identified in collaboration with company members through workshops, as well as document analysis. The key improvement opportunities were refined during stage three, through analysis and reflection on the Lean contributions to the BIM processes. The key improvement opportunities are associated with the process itself, the structure and transfer of information, and the standardisation and automation of time-consuming activities. The use of process mapping technique (1.c in Table 1) can support the definition of clash management activities sequence, identifying how the information moves from one stage to another, also defining clash detection and resolution frequency and cycles for each project. It can increase the transparency and process visibility (Klotz et al. 2008).

The early definition of standards of clash detection prerequisites, tolerances, and methods (1.b), e.g. templates and guides, have the potential to support the definition of criteria for clashes, and to define standardised set of rules per clash detection software in early stages, grouping clashes appropriately and avoiding rework. The early identification of client requirements (1.a) can also be achieved through a clear definition in the BIM Execution Plan (BEP) at the start of the project, e.g. providing an early definition of clash detection levels of detail and tolerances required by the client.

Table 1: Key clash detection and resolution activities and potential improvement opportunities.

	Key activities	Potential improvement opportunities
1.	Define and communicate the federation strategy (defined by the BIM execution plan)	**1.a Early identification of client requirements** within a clear definition of the BIM Execution Plan (BEP) at the start of the project. **1.b** Develop **standards**, e.g. templates and guides, to support the definition of clash detection prerequisites, tolerances, and methods. **1.c** Use **process mapping technique** to increase transparency, defining clearly how the information moves from one stage to another, also clearly defining the clash detection and resolution frequency and cycles.
2.	Generate models and prepare disciplines for federation *(design team)*	**2.a One-piece flow** to handle the clashes one-by-one as they are detected. **2.b Mistake proofing** to support BIM models' compliance, consistency and accuracy, avoiding element omission or duplication.
3.	Prepare federated model and federate discipline models	-
4.	Perform clash detection on federated model	**4.a Improved process standardisation** and **automated approach** for manual and repetitive clash detection activities, e.g. grouping or filtering the clashes.
5.	Report the clashes and analyse issues detected	**5.a Flow management and control approach, digital visual management and A3 reporting** can be adopted to improve clash management through automated systems, defining an interactive way to find, report and analyse the clashes and to improve transparency. **5.b Systematic waste analysis** through root cause analysis and clear definition of a clash classification criteria, identifying and reporting issues instead of clashes.
6.	Publish the federated model	-
7.	Organise and undertake regular design coordination meetings	-
8.	Resolve issues detected by clash detection, update and share updated models *(design team)*	**8.a Continuous improvement** to facilitate the exchange of lessons learnt between projects, using **Lean problem-solving techniques.**
9.	Update clash register and issue a report (if required)	-

In this study, the Lean ideal of one-piece flow (2.a) was identified as a potential approach to support the improvement of clash management, as a way to handle the clashes one-by-one as they are detected, avoiding a huge inventory of conflicts and eradicating the clashes as soon as possible. This approach would require the adoption of a federated model in which different disciplines can work on different parts of the model simultaneously without generating clashes, using a common data environment solution, which follows three states (work in progress, shared, and published) to manage the information (British Standards Institution [ISO] 2018). A mistake proofing approach (2.b) can potentially support BIM models compliance, consistency and accuracy through automation during design development, avoiding element duplication or omission, and drawing attention when the issues occur. It can support a clash avoidance process, in which an effort to avoid coordination issues exist during the design process.

There was an over-reliance on the technology for resolving the conflicts and some negligence when it comes to investigating the process itself to improve it. Thus, identify and report issues instead of clashes can potentially encourage people to focus on their design effort and reduce the reliance on software in that regard, in order to avoid clashes in the first place. A further improvement opportunity identified is associated with the occurrence of repetitive manual operations to input data in a clash register and analyse it. It was estimated that 30% of time can be saved through automation and standardisation of clash detection activities (4.a), e.g. automatic grouping of clashes. For instance, systematic generation of information is the anticipated improvement from the automation of the clash register, in which information can be visually displayed and effectively support clash analysis through a greater information transparency (5.a). Actions could be taken by identifying the root cause of the most common issues through a systematic waste analysis (5.b). The use of Lean problem-solving and continuous improvement techniques can facilitate the exchange of lessons learned between projects (8.a).

FINAL CONSIDERATIONS

The formalisation and standardisation of BIM processes can increase the transparency of the process, as described by Klotz et al. (2008), making the improvement opportunities and wastes apparent. Clash detection and resolution is an important and justified process in a Lean project delivery (Tommelein and Gholami 2012). The main improvement areas identified are related to the early identification of requirements for clash managenent, process standardisation, automation of time-consuming activities, information transparency with Visual Management, systematic waste analysis and continuous improvement.

The investigation also emphasised federation strategy as an essential fundament at the beginning of the design process. It should consider (i) the clash detection prerequisites, tolerances, rules, and methods; (ii) frequency of cycles; and (iii) how the resolution of clashes will be carried out, considering the stakeholders, actions, and root causes. The key root causes identified in this exploration represent a first step in the improvement of the existing taxonomies (Chahrour et al. 2021; Tommelein and Gholami 2012). Also, the identification of "intentional clashes" in practice is worth mentioning and calls for further investigation. In addition, it is important to highlight that there is still an excessive trust in technology for resolving the clashes and some disregard in improving the process itself. A lack of process-focus is evident from the study.

The findings indicate that Lean can contribute to BIM processes, beyond BIM capabilities and features (see Figure 5), supporting BIM process improvements. Until BIM and Lean (particularly considering Lean support for BIM) are implemented jointly as a standard practice in the sector, researchers and practitioners are encouraged to disseminate lessons learned and case studies, demonstrating how Lean techniques can improve BIM processes and providing evidence for higher quality outputs. For the Lean community to have a firmer place in the BIM community and discussions, and to be able to claim a mutual synergy between Lean and BIM, the wide range of intervention opportunities in BIM processes from a Lean perspective should be investigated further through a more systematic approach.

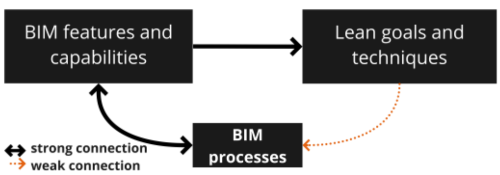

Figure 5: Lean goals and techniques contributions to BIM processes.

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