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Process Integration Framework for the Design Phase of a Residential Building

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Abstract

In Peru, the design phase of construction projects is frequently plagued by inefficiencies and poor coordination. These include clients' failure to communicate project goals; architects' and designers' frequent lack of understanding of said goals; and the failure to communicate learning loops from previous projects promptly to improve design quality. As such, it is argued that Building Information Modeling (BIM) helps to improve communication and visualization during the design process and opens a door to continuous improvement. However, the transition from traditional tools to a BIM-enabled process in the design phase is a challenging task. Many organizations are not prepared at the operational level to deploy BIM in synergy with current practices in the context of multiple stakeholders such as clients, designers, key suppliers, and constructors. The aim of this research is to develop a process-integration framework to improve visualization and communication in the design phase, aligning BIM, Project Management Book of Knowledge (PMBOK) areas (including scope, communication, and stakeholder management), and the learning loops of the Lean Project Delivery System (LPDS). The data collection is done by means of a case study in a residential building in Lima. Direct observation during the design phase will help to understand the process alignment. Lessons learned, barriers, opportunities, and guidelines for future research are discussed.

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Keywords: BIM; design management; PMBOK; LPDS; residential buildings.

1. Introduction

Experts in Building Information Modeling (BIM) claim that the use of this approach in construction has a positive impact on a project's costs [1], schedule [2], and building performance [3]. Fisher et al. [4] have argued that the

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earlier the decision makers and downstream stakeholders get involved, the better the performance in terms of cost, quality, constructability, and end-user satisfaction. During the design stage, information is shared by a number of stakeholders, including architects, designers, contractors, subcontractors, and potentially, users, in a looped fashion. When it comes to learning loops from previous projects, Lean Project Delivery System (LPDS) [5] offers an insight into how this information can be utilized as key inputs for both the project-definition and the design stages in a continuous value-added improvement process. Fisher et al. [4] have presented a framework of process integration in which knowledge from the construction and operations phases must be included early in the design stage to achieve a high performance building. However, in practice, teams struggle to integrate knowledge and information in a timely fashion early in the design stage. This lack of coordination within the construction industry is triggered by structural problems such as fragmentation, adversarial relationships, mistrust, and contractual relationships [6].

The Project Management Book of Knowledge (PMBOK) is a powerful framework that allows for control of all the relevant dimensions of the management of projects [7]. Through a series of tools and processes, PMBOK gives directions for project success. We argue that visual and communication management in design can be seen through the PMBOK lenses of scope, stakeholder, and communication management. On the other hand, Building Information Modelling (BIM) is a digital and managerial tool that is used to improve project visualization, information flow, system federation, planning, costing, and in general any prediction that relates to a project's goals [8]. However, incorporating these new tools into concomitant work processes appears to be difficult for design managers. Additionally, the transition from a CAD environment to a truly BIM design that includes all the relevant stakeholders appears to be a long-term process. With a number of exceptions, the literature on construction management lacks detailed research on the use of BIM in developing countries [9], and is almost totally devoid of information on Peru. This research intends to fill this gap. The objectives of this research are to (1) outline the results of a survey among AEC professionals on the relationships and characteristics of design management in a Peruvian context; and (2) develop a framework which integrates and aligns the main constructs of BIM with PMBOK's scope, stakeholder, and communication-management areas and the learning loops of LPDS. To achieve these objectives, first, we present the results of the survey depicting the current stage of design management. Second, we develop a framework for integration. Third, we conduct a qualitative case study by means of a residential project in Lima, Peru to gain insights on the proposed integration. Fourth, the results from the case study and lessons learned are discussed, and paths for further research are proposed.

Nomenclature

BIM	Building Information Modeling
PMI	Project Management Institute
PMBOK	Project Management Book of Knowledge
AEC	Architecture, Engineering, and Construction
LPDS	Lean Project Delivery System

2. Design Management in a Peruvian Construction Context

2.1. Stakeholder Communication Network

In the construction supply chain, the design phase consists of the network of first-tier stakeholders, including client, architect, designers, project manager, and contractor [6]. However, knowledge and information in the supply chain should also be shared with downstream stakeholders such as subcontractors, suppliers, and end-users to be fully effective [4]. To provide a picture of the communication network in a developing country, such as Peru, a questionnaire was designed to capture such relations during the design stage. Its questions had to do with the frequency of both virtual and face-to-face meetings, the means of communication, and the information-flow relationship. To collect data, one of the researchers, as part of her thesis, surveyed 122 AEC professionals in Lima, Peru that were working on residential, commercial, and retail projects. Figure 1 shows the communication network. Lines of different thicknesses depict the level of communication (tight ties, moderate ties, and loose ties). Especially noteworthy is the centrality to the network of the project manager—a contextual characteristic. Additionally, the results show the dramatic fragmentation of the constructors in the design stage, a quality mainly attributed to the project delivery method (e.g., Design-Bid-Build), and the lack of integration between key designers such as the electrical, mechanical, and plumbing engineers. This results in poor coordination, lack of information, and clashes detected later in the construction field.

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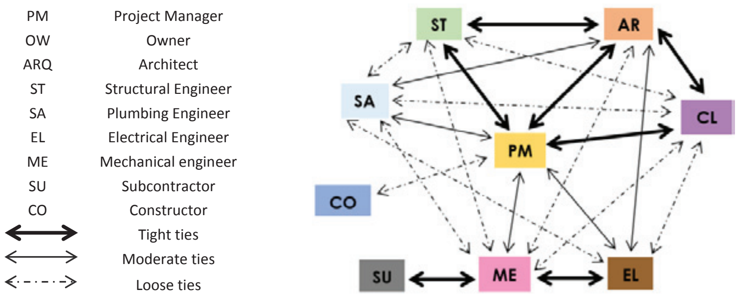


Fig. 1. Stakeholder’s Relationship Network in the Design Stage.

2.2. Visualization and Communication Management

The questionnaire explained above also had questions related to visualization and communication management in the design stage. Topics included tools, organization, and responsibilities. Table 1 summarizes the main questions and survey results. This information will serve as a basis for the development of the theoretical framework. The results also help to remedy the lack of evidence regarding the current situation of design management in Peru.

Table 1. Current Situation of Design Management in Peru.

Question	Survey Results
Contractor’s and subcontractor’s involvement in the design stage	In 70% of the projects neither the contractor nor the suppliers participate.
Number of face-to-face meetings with high attendance of stakeholders (>80%)	Up to two meetings in 40% of the projects.
Communication tools used in the design stage	E-mails, phone calls, face-to-face conversations, spreadsheets.
Visual tools used in meetings	AutoCAD and drawings in 80% of the projects.
Number of design alternatives discussed per system	Up to two alternatives in Architecture and Structural Systems.
Systems with the greatest number of conflicts and clashes detected in the design stage	Architecture vs. structural systems in 30% of the projects. Architecture vs. MEP systems in 34% of the projects.
Design management responsibility	Project manager in 65% of the projects. Architect in 35% of the projects.

3. Literature Review

Traditionally, the design stage has been divided into a feasibility study, predesign, schematic design, design development, and construction detailing [8]. The feasibility study deals primarily with cash flows, tentative project specifications, and initial cost estimates. In the predesign, the architect nails down the space and functionality requirements. This process is limited by building codes and zoning constraints. Schematic design includes the production of general drawings, the building shape, and identification of subsystems. However, in design development, detailed plans of systems (structural, lighting, mechanical, etc.) are elaborated. The construction detailing includes specification of systems and materials and of the connections among these various systems, as well as components detailing [8]. The scope of this research will include the predesign, schematic design, and design development stages, since the feasibility study deals more with cash flows and construction detailing with BIM in more mature markets.

The construction sector has been evolving in recent decades. Different techniques of administration and management of construction projects have developed over time to adapt to the technical and social novelties in the sector [10]. In addition to the changes undergone by the different management systems, there is a growing worldwide tendency for specialists in a given system to choose to integrate it with others, in order to unite their strengths and optimize the way in which they develop projects in their different phases [10]. Hartmann et al. [11] have argued that the implementation of BIM in construction practice promises to improve the communication and collaboration between participants. Also, to implement BIM on a construction project, it is necessary to configure and align BIM-based tools, project work processes, and business models for the companies that work together on a project

3.1. PMBOK and BIM alignment

The Project Management Institute is a nonprofit institution that has identified a set of knowledges, processes, skills, tools, and techniques that can have a considerable impact on the success of a project. These fundamentals have been translated as "Good Practices" in PMBOK, which provides a structured framework with all relevant dimensions for project success [7].

Independent of the project delivery method, the essence of the BIM methodology is to create networks of deep collaboration using the best possible technology, encouraging the early contribution of knowledge and experiences and actively involving the key participants starting in the initial stages [12]. BIM can be viewed as a technological transition for the AEC industry, specifically in the area of design practice [8]. Unlike the transition to CAD, BIM represents a paradigm change for stakeholder communication and interaction, as well as a change in the processes. Table 2 outlines the main BIM processes discussed by Eastman et al. [8].

The proposed synergy we will focus on includes the areas of scope, communication, and stakeholder management proposed by PMBOK, as well as the main applications of BIM during the design phase. Table 2 shows that BIM processes are aligned with up to two PMBOK processes. However, two PMBOK processes do not match BIM processes during the design phase. Additionally, PMBOK tools and techniques are focused on planning, execution, and control; only the tools called “Prototypes” can be used for visual management. BIM tools, though, are more focused on optimizing visualization and collaboration and are an effective complement to PMBOK tools as constructors seek to improve the complex interactions between stakeholders as well as visual management during the design stage.

Table 2. Processes Alignment.

Scope, communications, and stakeholder processes		BIM processes in the design stage [8]
Identify stakeholders	Plan stakeholder management	Earlier collaboration of multiple design disciplines
Plan communications management	Manage communication	Effective communication between multiple design disciplines
Collect requirements	Define scope	Earlier visualization of a design
		Generation and rapid evaluation of multiple design alternatives
-	-	Clash detection
Manage stakeholder engagement		Integrated concurrent engineering
Control communications	Control stakeholder engagement	-

3.2. Learning Loops of LPDS

In the LPDS, post-occupation evaluation is a feedback or learning loop that connects the end of one project with the beginning of the following one, thus promoting learning through the delivery process [13]. Stakeholder claims can be stored in an organization’s databases and catalogued according to their source—for instance, claims due to flaws in the delivery (use and maintenance), claims due to flaws in the production (construction), and claims due to flaws in the design. These claims’ root causes must then be discovered, and preventive measures must be taken, to avoid repetitions in future projects. An effective tool to determine the true reason for a problem is root-cause analysis, which can be adopted as a corrective measure for the design management system [14]. Learning loops are then treated as lessons learned, and performance information from previous projects (organizational process assets) [7] are used as inputs for process integration in the design stage. It is fundamental to combine the learning loops with the process integration during the design stage. In this case, the learning loops of LPDS are aligned with the organizational process assets of PMI.

4. Process Integration Framework

Table 3 shows the list of integrated processes, inputs, tools, and outputs for the theoretical framework proposed. As we can see, the outputs of some processes are considered inputs for downstream processes. Also, we consider it important to document the information garnered during the planning processes (early collaboration with stakeholders, communication, and project information model management). This information includes the following:

- For the early-collaboration stakeholder plan: a list of all the stakeholders identified, the stakeholder evaluation matrix, and all relevant information for subsequent processes compiled and defined by the project team (availability of time, geographical location of the work centers, communications media used by the organization, metrics to control the management of stakeholders and their frequency of monitoring).
- For the communication management plan: communication requirements and relevant information compiled and defined by the project team (main communication media selected for the project, communication metrics and their frequency of monitoring, communication protocols).
- For the BIM plan: requirements and relevant information compiled and defined by the project team (Level of Development, types of modeling and simulation software to be used, metrics of the model, frequency of measurement, type of model, i.e., federated or integrated).

Finally, as the main output of the entire design process, we will have the compatible BIM for the project; from this we can extract more complete documents and specifications for later stages.

Table 3. Process Integration Framework.

Integrated Process	Inputs	Tools	Outputs
Plan early collaboration of stakeholders	Project constitution, project delivery system, a team with experience in building projects and organizational process assets/learning loops.	Stakeholder analysis and analytic techniques.	Early collaboration stakeholder plan.
Plan communication management	Early collaboration stakeholder plan, a team with experience in building projects and organizational process assets/learning loops.	Communication requirements analysis and definition.	Communication management plan.
Plan project information model management	Level of detail (LOD) of the model, Work Breakdown Structure (WBS), early collaboration stakeholder and communication management plan, a team with experience in building projects and organizational process assets/learning loops.	Building information model of the project requirements analysis and definition.	Building information model management plan.
Scope definition, evaluation of multiple design alternatives	Early collaboration stakeholder, communications, and BIM plan, a team with experience in building projects, designers with experience using BIM technologies and organizational process assets/learning loops.	Client information requirement, WBS, 3D, 4D and 5D, group decision-making techniques.	Scope and requirements of the owner.
Multidisciplinary design meetings	Early collaboration stakeholder, communications, and BIM plan, a team with experience in building projects, designers with experience using BIM technologies and organizational process assets/learning loops.	Big Room and process mapping, requests for information (RFIs)	Compatible building information model of the project.
Clash detection	Early collaboration stakeholder, communications, and BIM plan, a team with experience in building projects, designers with experience using BIM technologies and organizational process assets/learning loops.	3D, Big Room	Compatible building information model of the project.

5. Case Study

The case study was carried out in the design stage of the residential building "Quinta Arrieta," located in the city of Lima. This six-story residential building covers 3,000 square meters and includes two basement levels, a roof-top area, and 15 luxury apartments. The data collection was carried out by one of the researchers via direct observation over a period of six months. The client hired the services of an architectural firm (VV) that usually uses BIM during the design stage. VV had the responsibility for the design management. Structural, electrical, mechanical, and plumbing designers were hired independently and directly by the client, but worked under VV's management.

5.1. Learning Loops

The design team visited an owner's previous project, which was developed in the same district and has similar characteristics. Architects and designers had the opportunity to see with their own eyes particular issues which were not taken into account in previous project designs. The owner, a real-estate developer, also expressed concerns about value loss due to some mistakes in the final product. For example, the lack of coordination between sewer and structural systems resulted in (1) construction problems in the field and beam perforation to allow pipe installation; or (2) headroom that was less than the minimum requirement in the building code. In other areas, the hanging sewer system allowed for the headroom required by the code (2.10 meters), but end-users who owned very tall automobiles complained that they could not place accessories on top of their vehicles. Other problems included the lack of power-generator support for essential elements (e.g., the elevator), problems in the drainage systems, electrical failures, and so on. The analysis is based on the understanding of the claims' root cause, collaborative discussions of how the problem could have been prevented, and what action should be taken to avoid repetition [14].

5.2. Planning

To ensure the early participation of stakeholders and commitment during the collaborative meetings of the design process, a clause was placed in the contract requiring participation in the weekly sessions. (This could be seen as arm-twisting, but it worked.) This contract management was similar to the collaborative meetings in the Last Planner System®, where constant cooperation with subcontractors is required [15], [16]. Additionally, different tools were used to ensure effective networks of communication during the design stage. Cloud-based storage and group communication tools were selected to provide the team with updates about the project. Furthermore, systems and sub-systems were identified collaboratively to ensure whole-scope definition. The client information was formally documented to ensure that the design was aligned with the owner's needs and values. Finally, the Work Breakdown Structure (WBS) was created and aligned with the BIM model plan. Said BIM plan considered modeling scope (systems, subsystems, and elements) and the level of development (LOD), which implies the level of specification and detail. It also included modeling responsibilities and the system-federation process. Finally, "Big Room" infrastructure was installed to allow the designers to meet in the same space. This included a meeting room, screens, and multimedia projectors.

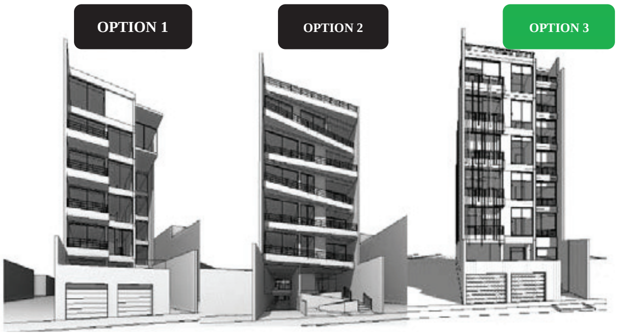
5.3. Execution

During the schematic design, multidisciplinary sessions with BIM models allowed for an analysis of the different architectural design alternatives. The visualization of the 3D model permitted stakeholders to make the best decision based on a set of options. One of the design analyses was based on the choice of the façade type, which took into account the amount of daylight let in, as shown in figure 2a. (Energy analysis was not performed for this case study.) Option 3 was chosen by the architects and accepted by the client.

During the design development, eight multidisciplinary design sessions were held at VV's offices (see figure 2b). These sessions were planned by the project manager, and the agenda was shared a day before the meeting. The commitments from previous meetings were highlighted to ensure the stakeholders were on task. Between meetings, communications were managed via the cloud-based project repository and the group communication system. The agenda prioritized hard clashes between systems and virtual tours to allow designers look at the systems virtually.

However, the system also allowed us to make improvements and added-value changes early in the design. For example, virtual tours allowed us to detect a vertical sewer pipe and mechanical ducts that were right in the middle of a parking space. This was not a hard clash, since building codes allow elements to "invade" a parking space if they do not reduce the space length by more than 5%. However, from the user's perspective, the pipe and ducts were both dangerous and inconvenient, in that they reduced the space available for the car. For this reason, all pipes were located between parking spaces. It was agreed that this improvement would not have been possible using only 2D drawings. Perhaps it would have even remained undetected until the building was in use. But in this case, the clash-detection process was performed, and the problem was resolved by designers in few minutes. One weakness of the case study was that the constructor was not formally included. However, this was not a major problem, due to the project manager's long experience in the construction of residential buildings.

a



b

Fig. 2. (a) Façade Design Options during Schematic Design; (b) Collaborative Meetings during the Design Development.

6. Results and discussion

BIM and its new managerial processes were incorporated into the planning, execution, and control areas during the design stage. In the planning stage, it was crucial to define the scope collaboratively with the owner, in order to meet the client-information requirement. As a result of this collaboration, the project manager was able to provide timely design criteria to the engineers before the design was carried out. For example, the client required socket plugs inside the closet cabinets to allow the end-user to install electrical de-humidifiers (Lima humidity is around 90% throughout the year). The requirement was formally written out and delivered on time to the electrical engineer and furniture designer to allow for coordination early in the design stage. It is also noteworthy that lessons learned arrived on time to the project team, who treated them as organization assets and a resource for continuous improvements. In the execution stage, stakeholders were integrated into several BIM models in the same physical environment. This allowed for effective visualization, improved communication, and reduced time in both RFI responses and information exchange. The design output was a federated BIM model, hopefully with fewer errors than in previous practice. In the control stage, the project manager managed to steer stakeholder participation and commitments during collaborative meetings. Also, the final BIM model was generated in accordance with the scope approved by the owner. A limitation of this study was that the impact on the construction process and end-user satisfaction was not assessed, since the project is still under construction. Another limitation is that subcontractors were not part of the design team. Their integration will definitely be part of future research.

7. Conclusions

The process-integration framework using BIM, PMBOK, and LPDS allowed for improved scope, communication, and stakeholder management. As a result, visual and communication management were also improved, as the project manager worked closely with stakeholders to reach the project's objectives in collaborative design meetings. The case study showed that management systems are compatible as the adaptation of processes can be carried out in a flexible way [17]. The framework includes a process in which the learning loops from post-occupancy issues and design errors are key inputs for a new project. As such, the design team considers needs and values of the owner and the end-user in a value-generation process. However, the design team also dealt with people's resistance to change. The research showed that 40% of the projects in the Peruvian AEC industry have only two meetings where all the relevant stakeholders attend during the design stage. In the case study, the owner changed the contractual system with designers in order to allow the project manager to steer the design process, secure designer's commitments, generate value, and reduce costs. In spite of contractual conditions that required multidisciplinary meetings, outsourced designers dealt with a resource-allocation problem. This can generate conflicts and fluctuations in the amount of work assigned, due to external projects in which stakeholders are involved [15]. In this context, partnering is a convenient contractual alternative to improve productivity and achieve regular workflows. Future research should address the impact of subcontractors' and suppliers' inclusion early in the design stage, and assessment of how improved design impacts both the construction process and end-user satisfaction. The use of Target Value Design (TVD) and Integrated Project Delivery (IPD), which require the use of BIM, should also be incorporated in developing contexts, such as Peru.

Acknowledgements

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