Murguia, D., Felix, K.M., and Guerra, M.A. 2020. "An Approach to Capture Design and Construction Lessons Learned from Facility Managers." In: Tommelein, I.D. and Daniel, E. (eds.). *Proc. 28th Annual Conference of the International Group for Lean Construction (IGLC28),* Berkeley, California, USA, doi.org/10.24928/2020/0067, online at iglc.net.

AN APPROACH TO CAPTURE DESIGN AND CONSTRUCTION LESSONS LEARNED FROM FACILITY MANAGERS

Danny Murguia[1], Kevin M. Felix[2], and Miguel A. Guerra[3]

ABSTRACT

The prevailing silo-way of working in the construction industry makes it difficult to incorporate valuable lessons learned from facility managers into the design stage of new projects. Some previous research in the lean community has studied methods to improve end-user satisfaction and lean principles to incorporate operations knowledge into design. However, studies focusing on problems during operation and maintenance (O&M) due to design and construction errors and the learning loops into the design stage are still lacking. This is an ongoing research project which aims to develop an open-source tool that can be used by design teams to incorporate knowledge from previous projects. This paper reports on a taxonomy of lessons learned and a preliminary tool structure. To achieve this, post-occupancy evaluation data were collected from office buildings in Lima. Ten facility managers were interviewed to describe the main challenges during O&M. It was found that lessons learned can be categorized as wrong design assumptions, design flaws, poor specifications, constructions flaws, and maintainability issues. Moreover, facility managers face with high maintenance costs and substantive building rework. A preliminary database structure to capture and retrieve O&M lessons learned is presented. Further research includes the validation of the tool with clients, project managers, and design teams; and the development of an online tool for industry engagement.

KEYWORDS

Lean construction, waste, continuous improvement, knowledge management, facility management

INTRODUCTION

Designs are becoming more complex and greater specification and performance are required. Some clients demand projects with increased safety conditions, energy savings, lower impacts on the environment, and end-user satisfaction. This implies greater participation of design consultants and therefore greater time in the design stage. The multidisciplinary design team has the responsibility to capture the needs and values of actors, who together with the regulations and site conditions, will serve as the basis for proposing design concepts (Ballard 2000). Nonetheless, the main characteristics of the

[1] Assistant Professor, Construction Management & Technology Research Group (GETEC), Pontifical Catholic University of Peru, dmurguia@pucp.pe, orcid.org/0000-0003-1009-4058

[2] Research Assistant, Construction Management & Technology Research Group (GETEC), Pontifical Catholic University of Peru, kfelixe@pucp.pe, orcid.org/ 0000-0002-3162-5711

[3] Research Assistant, Construction Management & Technology Research Group (GETEC), Pontifical Catholic University of Peru, guerra.miguel@pucp.pe, orcid.org/ 0000-0002-4148-182X

construction industry such as the focus on time and action, the late involvement of key stakeholders, and the prevailing silo-way of woking impede the timely incorporation of facility management knowledge in the design stage.

Buildings represent a significant financial investment to owners. Some research has shown that for each percent of design and construction costs are spent, up to 70% of its lifecycle costs are expected (Dahl et al. 2005). Ballard (2008) showed the relative costs of design and construction of healthcare estates in comparison with the costs of Operation and Maintenance (O&M) and business costs. For every 1.1 unit spent in design in construction, 4.3 units are spent in O&M, and 42 units are spent in organizational operating costs. Whilst these figures vary between industry and academic reports, the examination of operational costs when the facility is designed represents a potential for continuous improvement. Some property developers are mainly concerned with the return of investment during design and construction, whereas some other clients are only concerned with one-off projects to produce products or services (Ballard 2008). In the former, the bridge between design and operation is significant. In the latter, operations knowledge is an organizational asset. However, lessons learned and O&M expertise is hardly incorporated into new projects. Therefore, more research is needed to bridge the information divide between the design and operation of a facility (Dahl et al. 2005).

The challenge is hence how to transform O&M knowledge into explicit information for organizations and projects to reuse. Lin and Tserng (2003) presented five phases for knowledge management, namely, knowledge acquisition, knowledge extraction, knowledge storage, knowledge sharing, and knowledge update. As such, knowledge management aims at effectively and systematically capturing, collating, storing, and reusing information from past projects to reduce waste and cycle times, set benchmarks, and encourage continuous improvement (Lin and Tserng 2003).

Ballard (2000) claimed that feedback is an essential feature of the Lean Project Delivery System (LPDS). However, Roberts et al. (2018) pointed out a lack of academic interest in the use stage and post-occupancy evaluation (POE). Arguably, a systematic collection of O&M lessons learned is a rare practice. The challenge is to create an organizational database of O&M lessons learned which can be retrieved by design teams early in the design stage. This research aims to develop a web-based open-source tool that can be used by project teams in the design stage. The principle is knowledge sharing across organizational borders. This paper reports on the first stage of the project and presents a taxonomy of lessons learned and a preliminary tool structure.

LITERATURE REVIEW

O&M INFORMATION AND KNOWLEDGE

Bordass and Leaman (2005) argued that project actors do not engage with the performance of the buildings they have designed and built. The search and accumulation of this retrospective knowledge are hindered by a lack of interest in the interaction between the building and their occupants, and the unwillingness of clients to pay designers to undertake POE evaluations of similar projects. However, the knowledge accumulation of different projects presents an important source for competitive advantage (Lin and Tserng 2003). As such, the aim is to collect O&M information on repetitive projects to achieve reduced waste and generate greater value for the end-user. In other words, the success of the project will be determined by the degree of satisfaction that the client has with the completed installation, establishing whether or not it meets or exceeds their expectations (Grönroos 2000). For this reason, the design team must establish the customer's needs and values and select the best design alternative based on accurate, valid, and relevant lessons learned. Therefore, good decisions made at the beginning of the project can have a positive impact on the O&M stage (Dahl et al. 2005).

O&M issues typically represent the highest costs in the project lifecycle (Liu and Issa 2014). These operating and maintenance costs are defined at the early design stages, requiring high-quality information for greater benefit. Major positive changes in the initial phase, where flexibility is high and the cost of change is low, can reduce maintenance costs, reduce downtime, and improve security (Fitzgerald 2001). Therefore, the involvement of the facility manager in the design phase to reduce repairs and changes is encouraged (Mohammed and Hassanain 2010). Inadequate design for maintenance can lead to increased energy consumption, reduced occupant comfort, and premature failure of system components (Dahl et al. 2005). Despite the need for the above, the information provided in new projects is inaccurate or untimely (Whyte et al. 2012).

On the other hand, facility managers need a method for gathering information that helps to find operational issues, conflicts, develop new ideas, and identify customer needs (Kärna and Junnonen, 2005). As-built Building Information Models are a rich source of information. However, not all information received is valuable and facility managers will need to prioritize their information needs in detail. Construction Operations Building Information Exchange (COBie) is an interoperable data structure that facilitates the transmission of asset information (Hassanain and Vanier 2003). It was developed to provide a structure for capturing design and construction information to be handed to facility operators (East and Nisbet 2010). However, COBie captures data for asset management purposes only. The main problem is that most facility managers lack a scientific method to check and analyze the systems' and elements' functional performance. On the other hand, POE has a natural ability to provide an invaluable reflection on the performance of buildings (Roberts et al. 2019). This information is captured to improve operation efficiency (Mohamed 2018). Whilst COBie exhibits a forward flow of information, POE has the potential to exhibit a backward flow of information, thus, informing the design stage.

POST OCCUPANCY EVALUATION

POE is the process of systematically evaluating buildings after it has been used for some time (Preiser 1998). As such, POE collects built asset performance data and end-user satisfaction data. POE can serve a variety of purposes depending on the goals of the actor performing it (Preiser 2001). It can provide necessary data for the following:

- Ensure compliance with performance requirements;
- Execute small changes that provide improved functionality;
- Provide a better understanding of the effects of buildings on their occupants;
- Testing innovations in the building;
- Justify decisions and expenses; and
- Programming and continuous improvement of repetitive buildings;

POE helps to corroborate whether the assumptions on which the design, construction, and cost decisions were based were justified or not (Roberts et al. 2018). Corrective measures can be made if there is a gap between expected and actual performance. As such, POE aims to improve the quality and lifecycle costs of the existing building. Therefore, conducting POEs should be an integral component in the project delivery process and an industry practice (Bordass and Leaman 2005).

Roberts et al. (2019) found that the most prominent POE research has focused on the POE process and POE feedback. Moreover, most academic inquiry relates to technical performance and functional performance. Technical performance (e.g. such as energy consumption, indoor air quality, and thermal comfort) delve deep into objective data by assessing building performance against benchmarking criteria such as industry or client standards (Preiser 2001). Functional performance (e.g. space management, quality of finishes, comfort, function) relies on opinion surveys, interviews, workshops, and walk-throughs with end-users and facility managers (Zhang and Barret 2010). Nonetheless, Preiser (2001) argued that the end-user might have a technologically superior building, but a dysfunctional environment for people. This potential gap suggests that facilities are not necessarily achieving end-user satisfaction (Bou Hatoum et al. 2018).

Whilst technical performance can be better predicted with the use of sensors, big data, and enhanced norms and standards; functional performance requires a profound understanding of end-users' and facility managers' interaction with the building. Under this constructivist approach, rigorous and systematic post-occupancy lessons learned can be collected, managed, and reused in future projects (Lin and Tserng 2003). For this reason, the main task is to create a classification structure, a reliable way to collect data, and a user-friendly system that allows for information retrieval.

Based on Preiser (2001), Table 1 shows the types of POE. To achieve the research objective, an indicative POE is selected. Indicative POEs aims to investigate the main strengths and weaknesses of the building's performance through interviews with well-informed observers as well as a walk-through of the facility.

Table 1: Post-occupancy evaluation types (adapted from Preiser (2001))

Type	Focus	Type of data
Indicative	Indication of major issues with end-users and facility managers	Qualitative
Investigative	Understanding the causes and effects of problems	Quantitative and Qualitative
Diagnostic	New knowledge about building performance	Quantitative

RESEARCH METHOD

A qualitative method was selected as the research approach. Qualitative data helped to obtain rich information from experienced facility managers when facing challenges in O&M. A set of interview questions were designed to obtain in-depth knowledge from facility managers. The interview structure and content was informed by previous studies such as Loftness (2014), Abdou and Dghaimat (2016), and Strelets et al. (2016). The interview consisted of 40 questions grouped by building system in the following order: Architecture, Plumbing System, Electrical System, Lighting, Ventilation and Air Conditioning, Fire System, Accessibility, Elevators, Noise and Vibrations. Furthermore, questions included event details such as root cause, sources of waste, cost, impact on the operation, and end-user satisfaction. For example, some questions were:

- Has there been any refurbishment or additional work that has changed the initial building layout? Why the changes have been carried out? In what spaces have they been executed? What was the impact of the work? What long did it take? How much did it cost?
- Did you face any issues with the electrical system? Is it adequate for the proper operation of systems? Have you received any complaints from end-users about power supply issues? Have the causes been identified? Have any additional works been carried out to fix these issues?
- Has the air conditioning system presented any defect during operations? How often do you maintain the system? What is the maintenance cost? Have you received any complaints from end-users about ventilation and temperature issues in their office and/or communal areas?

The systematic collection of information was established in five phases, as shown in Figure 1. These include information acquisition, information parameterization, information storage, information retrieval, and use of information. This paper reports from "information acquisition" to "information storage."

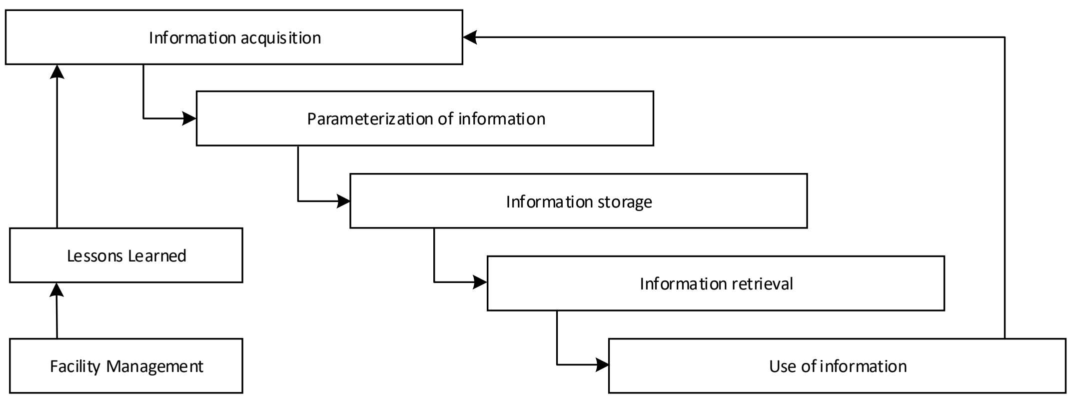

Figure 1: Information flow method (adapted from (Lin and Tserng 2003))

Invitation letters were sent to approximately 20 facility managers. The letter explained the research aim, objectives, and a confidentiality protocol. Some facility managers declined to participate due to not being authorized by owners to share building information. Ten participants representing ten multinational facility management companies were recruited for this study. Interviews were conducted between April and May 2019 by the second and third authors. Interviewees were asked to explain the challenges during the management of each building system. They also reported on some issues faced in other buildings under their management. Ten interviews with a total of 20 hours of recordings were collected. There were no request for sensitive information such as project name, developer, builder, district, or other information that would identify the project. All interviews were transcribed and anonymized. The audio recordings were destroyed. Transcripts were analyzed and 93 issues emerged.

RESULTS AND DISCUSSION

The office buildings studied were occupied by a single tenant (20%) and by multiple tenants (80%). 20% of the buildings have 10 stories or less, 20% had between 11 and 15 stories, and 60% had more than 15 stories. Facility managers had between 10 and 20 years of experience. This had significant impacts on the building operation and maintenance costs. The distribution of issues per building system is shown in Figure 2.

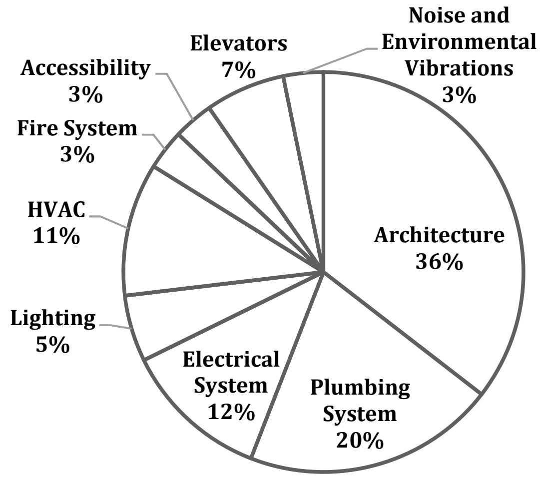

Figure 2: Distribution of issues per system

Data were also analyzed according to the severity of the issue (cost, re-work, and waste), and the impact on end-users. In terms of severity, serious issues require demolishing or rebuilding, moderate issues require replacement of individual components/systems, and minor issues require replacement of individual components/systems with minimal disruption to users. In terms of impact, serious issues are persistent and require tenants to be relocated temporarily, moderate issues cause a temporary closure of facilities or the utilities of the building will have to be turned off for the day, and minor issues are handled by facility managers on a daily basis with little disruption to users.

The results show that 34% and 42% of issues were serious in terms of severity and impact on users respectively, as shown in Figure 3. Table 2 presents 10 issues against system, severity, and impact on users.

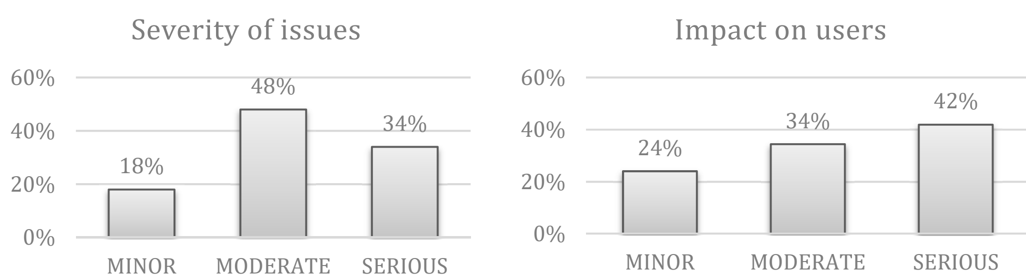

Figure 3: Distribution of issues by severity and impact on users

Table 2: Sample of issues per system and parameters

ISSUES	SYSTEM									PARAMETERS	
	Architecture	Plumbing System	Electrical System	Lighting	HVAC	Emergency System	Accessibility	Elevators	Noise and Vibrations	Severity	Impact on users
Insufficient power supply			X							S	S
Problems with vertical movement								X		S	S
Single water tank		X								Mo	S
Lack of water meters per office		X								Mi	Mo
Pipe corrosion		X								Mo	Mi
Vibrations caused by the chiller									X	Mo	Mo
Broken or obstructed foul pipes		X								Mo	Mo
Leaking water in concrete tanks						X				S	S
Difficulty to clean sloped curtain wall	X									Mo	Mo
Lack of hooks to install equipment to clean the curtain wall							X			Mi	Mi

S: Serious; Mo: Moderate; Mi: Minor

Finally, issues were deductively analyzed and five lessons learned categories emerged. Three categories pertain to the design stage, one category to the construction stage, and one category to the O&M stage, as shown below. Table 3 shows examples of each category.

- *Wrong design assumptions*: design criteria were unknown or not fit-for-purpose;
- *Design flaws*: designs badly elaborated or not according to standards;
- *Poor specifications*: incomplete or inaccurate design specifications of building elements and systems;
- *Construction flaws*: low-quality materials, equipment, or installation;
- *Maintainability issues*: difficult maintenance or maintenance that puts facility operators at risk.

Table 3: Taxonomy of lessons learned and examples

Type	Description	Consequence	Lesson Learned
Wrong design assumptions	Insufficient power supply	Substantive rework, Owner dissatisfaction	Study office occupant’s behavior to understand their power supply needs. Do not stick to the minimum requirements in electrical standards
	Problems with vertical movement	End-user dissatisfaction	Co-working spaces accommodate more people than originally designed. Long waiting times to take the lift
Design flaws	Single water tank	Rework, End-user dissatisfaction	Design independent tanks (water supply and fire system) to allow independent maintenance
	Lack of water meters per office	Rework, Owner dissatisfaction	Occupants need to know their water consumption. Do not stick to the minimum requirements in water supply standards
Poor specifications	Pipe corrosion	Rework	Specify alternative materials, such as PVC, for the main vertical supply
	Vibrations caused by the chiller	Rework, End-user dissatisfaction	Specify a base with springs that will absorb vibrations
Construction flaws	Broken or obstructed foul pipes	Rework	Implement a quality control protocol for horizontal and vertical foul drainage
	Leaking water in concrete tanks	Rework	A special treatment to concrete cracks and improve the waterproofing method
Maintainability issues	Difficulty to clean sloped curtain wall	Owner and end-user dissatisfaction	Cleaning a sloped curtain wall is costly and difficult to execute. Therefore, it is not cleaned regularly
	Lack of hooks to install equipment to clean the curtain wall	Owner dissatisfaction	Install hooks in the roof during the construction process

The proposed taxonomy could be seen as the highest level classification for lessons learned affecting building projects. Each issue can be described with the following fields: project type, lesson learned type, building system, component, location, description, root cause, consequence (cost and time), severity, impact on users, detailed solution, hyperlinks, and graphical information, as shown in Figure 4. Each issue and fields can be populated in the database. Data can be collected within a single organization, or across organizations. Project actors can filter tailored reports based on their needs. For example, a project manager would extract major issues of all systems, whereas the plumbing engineer would extract major issues in the plumbing system with high or very high impact on users.

The next step is to assure all aspects of data quality such as accuracy, validity, completeness, coherence, relevance, and timeliness. As such, the information retrieved will be fit for purpose, meaning that it will be useful for their intended users. For example, project type, building system, component, and location can be extracted from standardized classification systems such as Uniclass 2015. Furthermore, severity and impact on users can be assessed with objective metrics rather than subjective assessment.

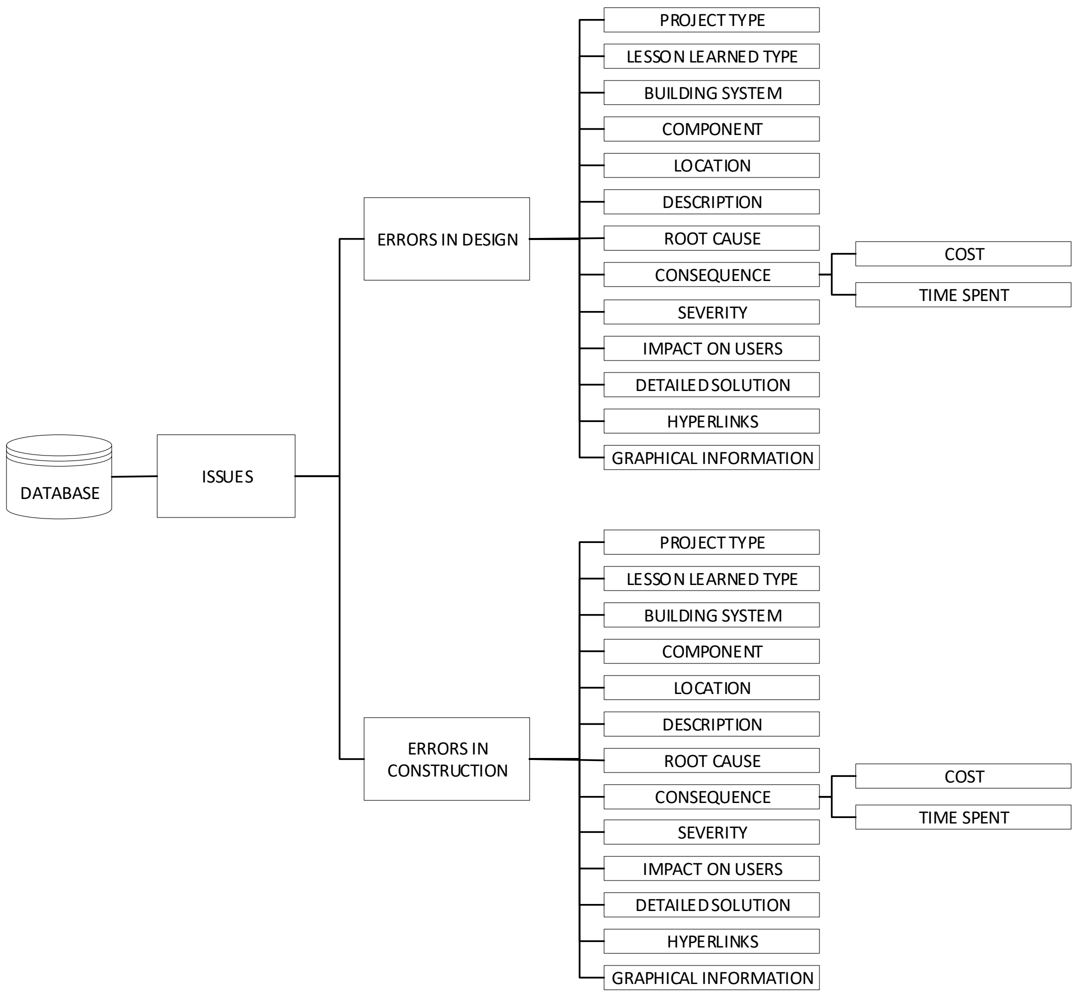

Figure 4: Database structure

CONCLUSIONS

The lessons learned from operations and maintenance are vital for continuous improvement in the delivery of built assets. Systematic and rigorous capture of indicative post-occupancy evaluation is not an industry practice. As such, this information is largely lost. Therefore, design teams rarely use O&M information about similar projects to inform their designs. This exploratory research aimed to create a database structure to systematically capture lessons learned from facility managers. 93 O&M lessons learned were collected from 10 facility managers of office buildings. The study showed that all buildings have issues in their operation due to problems in design, construction, and operations. The top two systems that account for more than 50% of O&M issues were the architectural system and the plumbing system (36% and 20% respectively). Some architectural problems appear only after two years of occupancy whereas plumbing system issues normally appear within a month of occupancy. Therefore, these two systems should be carefully examined by designers and builders. The data also showed five types of lessons learned, namely, wrong design assumptions, design flaws, poor specifications, construction flaws, and maintainability issues.

A database structure was proposed. The fields within the database include project type, lesson learned type, building system, component, location, description, root cause, consequence (cost and time), severity, impact on users, detailed solution, hyperlinks, and graphical information. The systematic record and management of these issues can have positive effects on project delivery of future projects. An open-source web-based tool can be further developed and tested with a community of research and practice to maximize the impacts of useful knowledge on decision-making in the design stage. Further research includes database population and information retrieval. Practitioners with a commitment to knowledge sharing across organizational borders will be incorporated into the project. Information retrieval will be tested with project managers and design teams. Project Managers would be responsible for presenting the tool to design teams which in turn would retrieve relevant information to make informed decisions about their designs.

REFERENCES

Abdou, A., and Dghaimat, M.A. 2016. "Post Occupancy Evaluation of Educational Buildings: A Case Study of a Private School in the UAE." *Proc. 4th Ann. Int. Conf. on Architecture and Civil Engineering (ACE 2016)*, pp. 114-120.

Ballard, G. 2000. *Lean Project Delivery System*. White Paper 8, pp. 1-6.

Ballard, G. 2008. "The Lean Project Delivery System: An Update." *Lean Construction Journal*, pp. 1-19.

Bordass, B., and Leaman, A. 2005. "Making feedback and post-occupancy evaluation routine 1: A portfolio of feedback techniques." *Building Research & Information*, 33(4), 347-352.

Bou Hatoum, M., El Mustapha, R., Nassar, C, Zaheraldeen, H., and Hamzeh, F. 2018. "Lean Methods to Improve End-user Satisfaction in Higher Education Buildings." *Proc. 26th Ann. Conf. Int. Group for Lean Construction*, Chennai, India, pp. 187-198.

Dahl, P. K., Horman, M. J., and Riley, II, D. R. 2005. "Lean principles to inject operations knowledge into design." *Proc. 13th Ann. Conf. Int. Group for Lean Construction*, Sydney, Australia, pp. 431-436.

East, E.W. and Nisbet, N. 2010. "Analysis of life-cycle information exchange." *Proc. Int. Conf. on Computing in Civil and Building Engineering*, Nottingham Univ. Press, Paper No. 75, p. 1-7.

Fitzgerald, A. 2001. "Design for maintainability." *START*, Vol. 8 No. 4, pp. 1-4.

Grönroos, C. (2000). *Service Management and Marketing: A customer relationship management approach*. 2nd ed., John Wiley & Sons, Ltd.

Hassanin, M.A., Froese, T.M. and Vanier, D.J. 2003. "Implementation of a distributed, model-based integrated asset management system." *J. of Information Technology in Construction*, Vol. 8, pp. 119-134.

Kärnä, S. and Junnonen, J. 2005. "Project Feedback as a Tool for Learning." *Proc. 13th Ann. Conf. Int. Group for Lean Construction*, Sydney, Australia, pp. 47-55.

Lin, Y. and Tserng, H.P. 2003. "Knowledge Management and its Application to Lean Construction." *Proc. 11th Ann. Conf. Int. Group for Lean Construction*, Virginia, USA, 1-12.

Liu, R. and Issa, R.R.A. 2014. "Design for maintenance accessibility using BIM tools." *Facilities*, Vol. 32, No. 3/4, pp. 153-159.
Loftness, V. (2009). "The Value of Post-Occupancy Evaluation for Building Occupants and Facility Managers." *Intelligent Buildings International*, Vol. 1, pp. 249-268.
Mohammed, A. B. 2018. "Developing Post-Occupancy Evaluation using Value Engineering in the Higher Education Buildings." *Int. J. of Engineering Research and Technology*, Vol. 7, No. 12, pp. 67-77.
Mohammed, M. and Hassanain, M. 2010. "Towards improvement in facilities operation and maintenance through feedback to design team." *J. Built and Human Environment Review*, Vol. 3, pp. 72-87.
Preiser, W.F., Rabinowitz, H.Z. and White, E.T. 1998. *Post-Occupancy Evaluation*, New York: Routledge.
Preiser, W.F. 2001. "The evolution of post-occupancy evaluation: towards building performance and universal design evaluation." *Learning from our Buildings*, pp. 19-28.
Roberts, C.J., Pärn, E.A., Edwards, D.J. and Aigbavboa, C. 2018. "Digitalising asset management: concomitant benefits and persistent challenges." *Int. J. of Building Pathology and Adaptation*, Vol. 36, No. 2, pp. 152-173.
Roberts, C. J., Edwards, D.J., Hosseini, M.R., Garcia, M.M. and Owusu-Manu, D. 2019. "Post-occupancy evaluation: a review of the literature." *Engineering Construction & Architectural Management*, Vol. 26, No. 9, pp. 2084-2106.
Strelets, K., Perlova, E., Platonova, M., Pankova, A., Romero, M., and Al-Shabab, M. 2016. "Post Occupancy Evaluation (POE) and Energy Conservation Opportunities (ECOs) Study for Three Facilities in SPbPU in Saint Petersburg." *Procedia Engineering*, Vol. 165, pp. 1568-1578.
Whyte, J., Lindkvist, C. and Hassan Ibrahim, N. 2012. "From projects into operations: Lessons on data hand-over." *Management, Procurement and Law*, Vol. 166, No. 2, pp. 86-93.
Zhang, Y. and Barret, P. 2012. " Findings from a post-occupancy evaluation in the UK primary schools sector." *Facilities*, Vol. 28, No. 13/14, pp. 641-656.

This page was intentionally left blank.