EUBIM 2019

Congreso Internacional BIM 8º Encuentro de Usuarios BIM

BIM INTERNATIONAL CONFERENCE

Just do BIM

Valencia 23, 24 y 25 de mayo 2019

LIBRO DE ACTAS

Entidades Participantes:

GURV

CAMINOS UPV

DEPARTAMENTO DE CONSTRUCCIONES ARQUITECTÓNICAS

ESCOLA TÈCNICA SUPERIOR ENGINYERIA D'EDIFICACIÓ

COLEGIO INGENIEROS INDUSTRIALES COMUNITAT VALENCIANA

CAATIE VALENCIA Colegio Oficial de Aparejadores, Arquitectos Técnicos e Ingenieros de Edificación de Valencia

CITOPIC

Consejo General de la Arquitectura Técnica de España

CTAV COLEGIO TERRITORIAL DE ARQUITECTOS DE VALENCIA

Organizadores:

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

anys

www.EUBIM.com

EUBIM 2019

Congreso internacional BIM
8º Encuentro de usuarios BIM

Valencia, 23, 24 y 25 de mayo de 2019

Editorial
Universitat Politècnica
de València

Congresos UPV

EUBIM 2019. Congreso Internacional BIM / 8º Encuentro de Usuarios BIM

Los contenidos de esta publicación han sido evaluados por el Comité Científico que en ella se relaciona y según el procedimiento que se recoge en http://www.eubim.com

Edición Científica

Begoña Fuentes Giner
Inmaculada Oliver Faubel

Comité Organizador

Manuela Alarcón Moret
Alberto Cerdán Castillo
Amparo Ferrer Coll
Begoña Fuentes Giner
David Martínez Gómez
Inmaculada Oliver Faubel
Lorena Soria Zurdo
José Suay Orenga
David Torromé Belda
Sergio Vidal Santi-Andreu

Edita

Editorial Universitat Politècnica de València, 2018
www.lalibreria.upv.es / Ref.: 6546_01_01_01

ISBN: 978-84-9048-805-8

ÍNDICE DE COMUNICACIONES Y PONENCIAS

1. FORMACIÓN E INVESTIGACIÓN EN BIM

2 DISEÑO Y CONSTRUCCIÓN CON BIM

3. EXPERIENCIAS REALES CON BIM

Post-occupancy evaluation and BIM methodology: a state of the art of predictive information for building management system

Pellegrini, Laura[a]; Di Giuda, Giuseppe Martino[a]; Schievano, Marco[a] y Locatelli, Mirko[a]

[a]Department of Architecture, built environment and construction engineering, Politecnico di Milano, Italy
laura2.pellegrini@mail.polimi.it

Abstract

This research aims at investigating the application of Post-Occupancy Evaluations (POE). The operational phase has the maximum impact on costs during the life of a building. It is essential to optimize building performances during this phase to ensure functionality and efficiency. POE are mainly used to define energy performances, but other aspects have impacts on functionality and consumptions: effective occupants' behaviour, usage models and supplies planning. The application of POE on existing buildings can provide information on actual uses, supply needs and users' behaviour. The goal of this paper is to provide a complete state of the art about POE fields of use and tools currently used to perform POE combined with BIM methodology. A literature review in national and international contexts can find opportunities and weaknesses about current uses of POE. A main aspect is the large amount of data collected during POE. The research intends to explore the potential application of IoT sensors and Machine Learning techniques to POE. Further developments are the application of POE to bridge the gap in the process of digitalization of the operational phase, providing predictive information for building management.

Keywords: *Post-occupancy Evaluation; operational phase; IoT sensors; Machine Learning; digitalization; performances optimization.*

Resumen

Esta investigación tiene como objetivo la aplicación de las Evaluaciones de Post-ocupación (POE). La fase operativa tiene el máximo impacto en costes durante la vida útil de un edificio. Es esencial optimizar las prestaciones durante esta fase para garantizar funcionalidad y eficiencia. Los POE se utilizan principalmente para definir el rendimiento energético, pero hay otros aspectos que influyen en la funcionalidad y los consumos. La aplicación de POE en edificios existentes puede proporcionar información sobre los usos reales, las necesidades y el comportamiento de los usuarios. El objetivo de este trabajo es proporcionar un estado del arte sobre los campos de uso de POE y las herramientas utilizadas para realizar POE en combinación con metodología BIM. Una revisión de la literatura en contextos nacionales e internacionales puede encontrar oportunidades y debilidades sobre los usos actuales de POE. Un aspecto principal es la gran cantidad de datos recopilados durante POE. La investigación pretende explorar la aplicación potencial de los sensores de IO y las técnicas de aprendizaje automático a los puntos de entrada. Otras novedades son la aplicación de POE en el proceso de digitalización de la fase operativa, proporcionando información predictiva para la gestión de edificios.

Palabras clave: *Post-occupancy Evaluation, fase de operación, sensores IoT, Machine Learning, digitalización, optimización del rendimiento*

Introduction

During the life of a building, costs associated with the management phase have a significant impact on the total cost of the building life cycle. Several analyses carried out since the 1990s established a ratio of 1:5:200 over the life of a 30-year-old office building, in relation to construction, maintenance and operating costs respectively (Wu and Clements-Croome 2007; Evans et al. 1998). It can be seen that the operational and use phase has a significant impact on the costs over the life cycle of a building.

It is necessary to optimise the process of building management during the operational phase in order to ensure functionality and efficiency of buildings. The optimization of this phase could result in several advantages:

- savings in operating costs;
- efficient building management;
- functionality of the building;
- increased satisfaction of users.

It is clear that efficiency and functionality of an organization can be strongly influenced by a space (Zimmerman and Martin 2001). In terms of costs, energy and time, as well as in terms of resources, the way occupants use spaces can produce higher consumption. This can lead to additional costs in terms of building management or to lower quality of the available services and resources, resulting in low user satisfaction. Unless these aspects are managed, it is even hard being aware of the possible damages in terms of quality or higher costs. Traditionally more emphasis is given to monitoring compliance with requirements and objectives in the design and construction phases, reducing the gap between expected and actual quality. During the operational phase, the actual quality is not often checked. In most cases the building is a prototype of itself with regard to the actual use (Zimmerman and Martin 2001).

Leaman et al. pointed out the experience of AEC industry specialists in the design and construction phases. However, despite the shared belief of even government, they are neither interested in usage patterns of buildings in use nor in the analyses of building performance and weaknesses, once occupied (Leaman et al. 2010).

Unlike usual practice, RIBA's first handbook (1965), within the final stage of the "Plan of work", focuses on feedback. This evaluative process was regarded as "the most cost effective way of improving service to future clients" (Royal Institute of British Architects (RIBA) 1965; Cooper 2001). Despite this, the evaluation of feedback, once the building is used, is not yet widespread.

In this context, post-occupancy evaluations (POEs) can be a means of improving the above issues. POEs are "examinations of the effectiveness for human users of occupied design environments" (Zimring and Reizenstein 1980). As a matter of fact POE has been occasionally called "building-in-use-studies"(Preiser 2010). The POEs have the following peculiarities (Leaman et al. 2010):

- They are used to solve problems.
- They provide predictive data, not just the causes of a phenomenon or result found.
- They collect robust data, not just statistical data, on usage patterns.
- They can be applied to real cases; they are not limited to scientific experiments.
- They need the cooperation of the users and occupiers.
- The lower the costs and the shorter the application time, the better; even better considering users' discomfort POEs can produce.

The aim of this work is to provide a brief review to evaluate and clarify the state-of-art about post-occupancy evaluations. A systematic approach has been adopted to review related publications in order to identify what POEs are and what they are used for. After an analysis of drivers and barriers to the dissemination of POE, a review is given to highlight research gaps and possibilities for future research and development.

1. Historical background

The first step of this research id the identification of needs that first led to the use and definition of evaluations. This made it possible on the one hand to assess the driving factors and, on the other hand, the obstacles to the widespread use of POEs.

Historically, the performance of buildings has been assessed informally and lessons learned have been applied in the subsequent construction cycle of a similar structure. Building specialists had multiple skills ranging from architectural, aesthetic, technical knowledge to the information about the future use of the building. Due to relatively slow changes in the evolution of building types in the past, knowledge about their performance and use has been passed on from one generation of building specialists to the next. (Preiser 2010)

Nowadays, there is a multitude of building specialists taking part in the building life cycle. Each of them has its own targets to achieve and requirements in terms of building performance, as well as outlook, technical language and incentives to achieve their goals. At the same time, clients are placing ever-increasing and different demands on buildings (Preiser 2010). Besides this, it must be considered that in many cases the requirements of clients and specialists involved in the design and construction phases are different from users' needs (Zimmerman and Martin 2001).

As shown above, before the building is used, it is hard to define whether the building features and performance ensure its functionality and efficiency, as well as user satisfaction.

For this purpose, the first applications of the POEs started in the 1960s for performance analyses of large government facilities with a perspective on occupants needs and satisfaction (Preiser 2010). The major development of these methodologies in terms of theory and strategy was carried out from the 1980s, as a tool for facility management and design.

In the next sections, drivers and barriers related to POEs uses are presented, with the aim of understanding their still limited application to buildings' life cycle phases.

2. Drivers

2.1. Continuous improvement

POEs can provide large amount of data relating to actual uses of spaces, supply needs and users' behaviour: these aspects have strong impacts on functionality and consumptions of a building (Bento Pereira et al. 2016). From an architectural perspective, the Royal Institute of British Architects defined POE as "a systematic study of buildings in use to provide architects with information about the performance of their designs and building owners and users with guidelines to achieve the best out of what they already have" (Royal Institute of British Architects (RIBA) R.S.G. 1991).

This means that POEs can provide valuable information for the continuous improvement of the building operational stage, the short-term benefits from POE application as defined by Preiser (Zimmerman and Martin 2001; Preiser 2010).

Among the main benefits, the analysis of POE data can indeed produce valuable information to provide predictive information (Leaman et al. 2010) for building management during the operational phase. The facility manager can define the usage pattern of the building, thereby defining accurate and specific management plans.

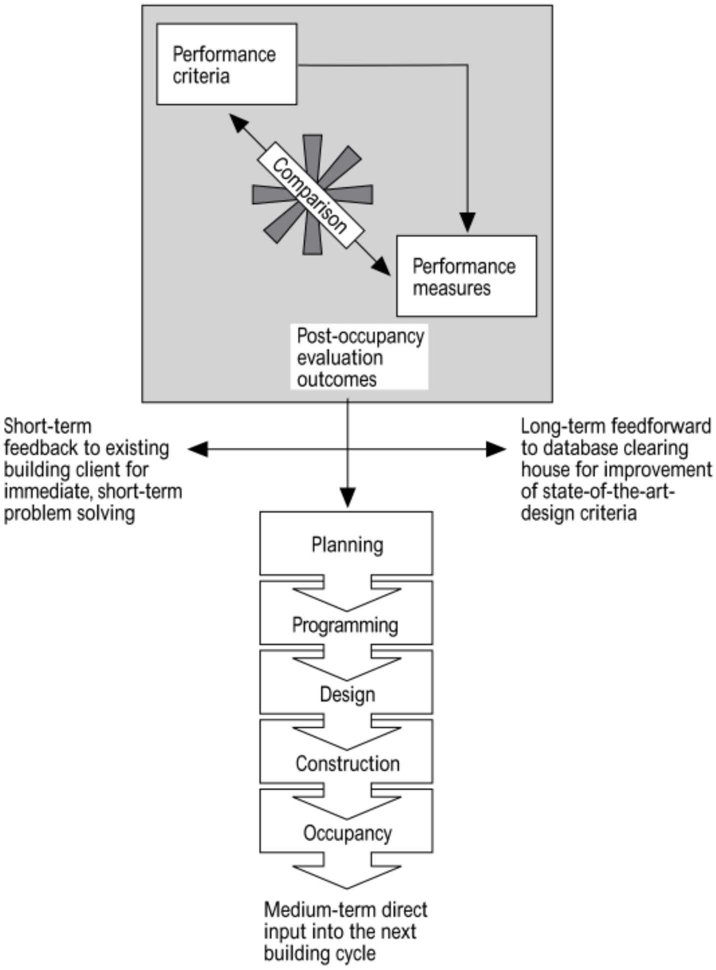

Fig. 1: Short-term, medium-term and long-term benefits of POEs. Reference: Preiser, W.F.E. (2010)

2.2. Increased user satisfaction

Data collected from POEs are valuable to designers and building specialists. POEs lead to the definition of a database with information about occupation, actual needs of users, usage patterns, resources and facilities required for the building operational phase. These aspects have a high dependence on users' age, features and needs and the way occupants use a building can produce even more or less user satisfaction and resultant more or less comfort, wellness and even productivity at work.

One of the main benefits and aims of POE is the increase of user satisfaction. Zimmerman and Martin stated that "POE typically focuses on assessment of client satisfaction and functional 'fit' with a specific space" (Zimmerman and Martin 2001).

One of the ways to ensure user satisfaction is to conduct POEs to determine if the occupants got what they expected, and use the results to both rectify shortcomings and inform the next design, the medium-term benefits from POE application as defined by Preiser (2010). POEs allow to collect a wide range of data and can lead to improvements in existing buildings, as mentioned above, thus generating greater user satisfaction.

2.3. Feedback for design process

Feedback from existing buildings is one of the greater advantages in the use of POEs. Post-occupancy evaluations allow to learn from the past and evaluate current trends (Preiser 2010; Agyefi-Mensah et al. 2013). Spaces of an existing and occupied building not producing the expected function can therefore be eliminated or modified in the next design according to actual needs (Zimmerman and Martin 2001). As a result, future occupants will be considerably more satisfied and will increase efficiency in the use of the building.

Moreover, POEs have evolved from individual and simple case study to sophisticated and transversal studies of several building types with valid, reproducible and generalizable results. Database of information collected through POEs can be the basis for the definition of design criteria and guidelines (National Research Council 1987; Preiser 2010) relating to the function of the building as well as to the type of users, the long-term benefits from POE application as defined by Preiser (Preiser 2010). With designers using this kind of criteria and guidelines, next clients can both save money and achieve more efficient buildings that match the expected functions. As a result, lessons learned from buildings in use can feed into the optimisation and improvement of future buildings (Leaman et al. 2010).

In addition, the increased knowledge can be used to improve the next project and to gain a competitive edge over other specialists and designers who have not had any feedback from their previous projects regarding the operational phase. This should result in increased fees or additional work, as well as better future designs.

2.4. Reduction of energy consumption

POEs analyse the actual use of buildings, user behaviour and user satisfaction, as well as the energy performance of the building. This kind of analyses, carried out with the support of data from IoT sensors, allow the definition of the effective energy performance of a building. The results of the POE are compared with the building performance as obtained through simulations during the design phase (Straka and Aleksic 2009). POEs help determine whether the initial conditions ensure comfort and user satisfaction in the operational phase. On the other hand, POEs can highlight the influence of users' effective behaviour on usage patterns and consumption of the building. (Straka and Aleksic 2009).

The analyses focus on energy consumptions in terms of heating, cooling and indoor air quality. To date, the focus on green buildings leads to increased interest in these aspects (Leaman et al. 2010). This means that POEs carried out for this purpose are more frequently used, mainly by means of sensors (Marzouk and Abdelaty 2014; Costa et al. 2015; Demian et al. 2018). In addition, benchmarks and standards are available for energy performance and indoor air quality monitoring. As a result, it is easier to define whether the building's performance is negative or positive.

2.5. Reduction of costs of the operational phase

As mentioned in a previous paragraph, feedback from existing buildings ensures savings in future buildings: unoccupied areas or spaces that did not fit the function can be removed in future designs. This allows customers to save money or achieve a more efficient building, with lower need for adjustments once occupied.

On the other hand, an efficient use of buildings also leads to cost savings in terms of resources, cooling and heating costs during the operational phase of existing buildings. An in-depth analysis of actual uses of existing buildings would make it possible for example to limit cooling and heating only to the occupied areas and thus optimise consumption in terms of costs. Similarly, would be possible to optimise the use of resources and spaces management, as well as cleaning activities, which are often extended to all rooms, i.e. in schools and office building, regardless of their actual use.

3. Barriers

3.1. Standard practice

Traditionally, once the building is occupied, it is not expected a process of continuous improvement or verification of compliance with expected targets for the operational phase (Zimmerman and Martin 2001), as well as the evaluation of users' satisfaction. There is even institutionalized pressure in the AEC industry to carry on with standard practice and not to innovate, which comes from a number of areas, mainly to avoid any delay in financing, approvals or design process (Lovins 1992).

This results in POEs not yet becoming a standard in common practice, despite the advantages introduced in the previous section. Some other obstacles to the spread of POEs are presented below.

3.2. Benchmarks

Performing analyses such as POEs requires benchmarks against which to compare the data collected. The lack of indicators precludes the definition of whether POEs show positive or negative results.

As shown previously, the AEC industry involves several building specialists taking part in the building life cycle. Each of them has its own goals to achieve, as well as targets in terms of building performance. Clients are usually more interested in obtaining a building at the lowest construction cost and do not care about building performances or uses during the operational phase. Typically, the criteria of judgement for POEs are the compliance with functional programmes and users' needs (Zimmerman and Martin 2001). However, it is hard to define the occupants' needs, nor if the functional program meets them. As a matter of fact, the benefit perceived by the user of a space or building may not necessarily be the same as that of designers or owners (Bordass et al. 2001; Zimmerman and Martin 2001). Therefore, the functional program as defined during the design phase may be in contrast with the users' needs in the operational phase. In addition, users' needs highly depend on their age, features, occupation, etc. (Bento Pereira et al. 2016). It is a slightly different case for POEs that analyse energy performance and monitor indoor air quality. As already stated, benchmarks and standards for this kind of analyses are widely used and frequently regulated.

As a result, it is quite difficult to define unique and shared targets and building performance requirements. The fragmentation of the AEC industry and the lack of shared goals among the actors involved in the various building life cycle phases, results in a huge effort to define benchmarks. Furthermore, benchmarks should be defined in relation to each type of building, whether residential, service or commercial buildings.

POEs can collect a large amount and variety of data with a considerable impact on the cost of performing them. As a consequence, the lack of awareness of the main objectives leads either to the collection of useless data or to over-detailed analyses. The result is the increasing of costs and complexity of POEs, limiting even more the application of this kind of analyses.

3.3. Liability

The resistance of AEC industry in the use of POEs comes even from liabilities resulting from an awareness of the real conditions of buildings. Actually, POEs could highlight some current issues of existing buildings: low user satisfaction, usage patterns producing waste of energy and resources, as well as poor indoor environmental conditions and inefficient energy performances.

Several rented out building owners will be reluctant to carry out analyses such as a POEs that could reveal weaknesses of their building compared to similar ones. As a result, Zimmerman and Martin pointed out that tenants would move out, producing a reduction in revenue. They define this mentality as "ignorance is bliss" (Zimmerman and Martin 2001): building managers and owners reject innovative methods that generate better or more complete information, since they can result in lower profits.

3.4. Users' reluctance

A further area of concern is the reluctance of users to take part in this kind of analyses. POEs can easily appear as a discomfort and a restriction on user privacy. This has a strong impact on the selection of how a POE is performed.

In this context, Preiser (2010) defines three levels of detail of POEs (Preiser 2010):

- Indicative POEs: these are non-invasive analyses; interviews and on-site photographic surveys are used.
- Investigative POEs: these are more in-depth analyses; questionnaires, video recordings and point measurements of indoor environment or energy performance are added.
- Diagnostic POEs: these are detailed analyses; they involve widespread and continuous monitoring, defining consistent databases.

The more in-depth and invasive the analyses are, the more reluctant users will be. This is the reason why indicative POEs are often used for an overall analysis of the building to identify the main issues. The most critical areas and aspects are therefore object of more in-depth analyses, which can even take much longer to apply than indicative POEs.

3.5. Implementation costs

Costs of carrying out analyses are an additional barrier to the spread of POEs. Monitoring by means of sensors and other types of devices can be expensive when it comes to large buildings: Preiser (2010) identifies the costs of POEs according to the level of detail (Preiser 2010).

It is clear that costs of application are a further obstacle to the spread of POEs and, as mentioned above, researchers should consider a level of detail according to the criticism detected with a basic survey. This avoids collecting unnecessary and oversized data on lower critical areas or topics.

4. IoT sensors and machine learning application

Another issue that cannot be ignored is the following: to ensure the effectiveness of POE, it is necessary to collect and analyse a sufficiently large set of data. The application of IoT sensor systems can be useful to this purpose as it defines a measurement technology (Preiser 2010). This is a rapidly expanding technology in many contexts and is now consolidated with numerous research and applications in the optimization of energy performance.

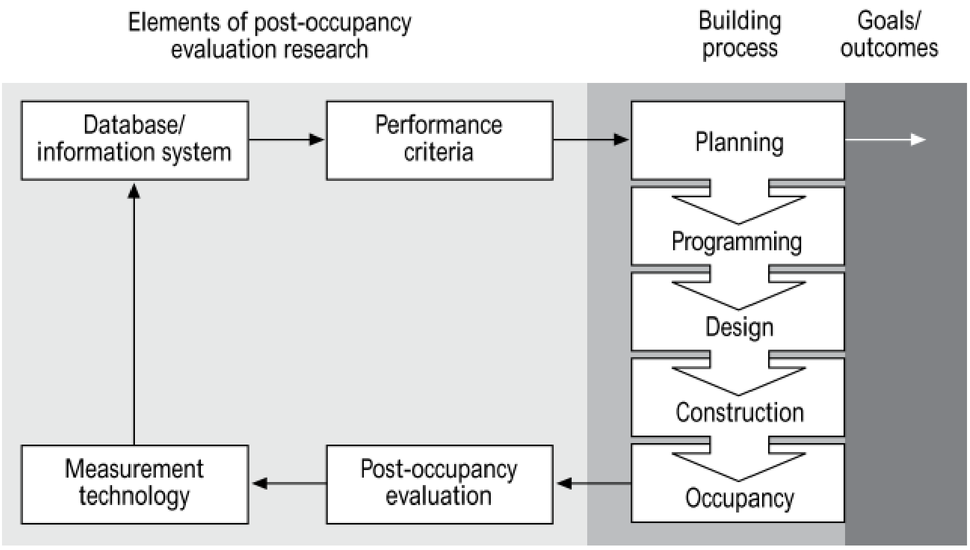

Fig. 2: Inputs and elements of POEs. Reference: Preiser, W.F.E. (2010)

An in-depth analysis of several publications (Demian et al. 2018) dealing with the integration between sensors and BIM methodology showed these results: it was identified that a limited number of publications dealt with the use of sensors in the operations and maintenance phase (23%) and in the tracing of people and facilities (12%). It is clear that data provided by the sensors and structured can be then integrated with the building information model; sensors data, saved in the building model, become valuable to keep the information accurate and up-to-date (Underwood and Isikdag 2011).

Nonetheless a deep analysis with sensors, besides being limited to critical areas, could involve a huge quantity of data, as a result of the integration of POEs analyses with IoT sensors systems. To date, there is an imbalance between data acquisition and analysis (Ahmed et al. 2017), so it is also necessary to define a system for the classification and analysis of large amounts of data. These structured data can be fed to an artificial intelligence based on machine learning methods (ANN). This could bring to predictive information for an improvement of building performance and use, that is one of the main goals of POEs.

5. Conclusions

Drivers of POEs shown how useful this type of analysis could be to improve existing and future buildings. Barriers, on the other hand, highlighted several limitations to the spread of POEs.

The research gap identified can be resumed in the following elements:

1. Need to set benchmarks to compare with data collected through analysis.
2. Make owners and managers aware of the considerable savings that result from the application of POEs. At the same time, there is a need to reduce the perceived fear of POEs producing a decrease of profits. Analyses, indeed, may initially highlight shortcomings and problems, but once solutions are identified, increased user satisfaction and predictive information relating to building management during the operational phase can lead to benefits such as:
    - Improving users’ satisfaction, morale and even productivity at work.
    - Cost savings in maintaining and operating facilities over life cycles, coming from an efficient use of spaces and resources.
3. Find the best method of carrying out the analyses depending on lower discomfort and limitation of users' privacy. The optimization of the costs of POEs implementation can also be achieved according to desired outcomes and weaknesses detected.

POEs could represent an answer to proposed issues, both through questionnaires and interviews to evaluate users’ satisfaction, and by means of sensor for environmental condition analysis. This approach could bring to a complete definition of an existing building’s conditions. The integration of POEs, IoT sensors technology and Building Information Modelling could result in a better structuring, archiving and continuous updating of data coming from POEs.

Further developments may be the use of machine learning techniques in order to accurately analyse data and to define predictive information for the operational phase of a building. The application to a case study will allow to define advantages, disadvantages and complexities of the defined method. At the same time databases from POEs on existing buildings will be used to define guidelines for future buildings implementation.

6. References

AGYEFI-MENSAH, S., POST, J., VAN EGMOND, E., BADU, E. and MOHAMMADI, M. (2013). “The Need for Post-Occupancy Evaluation of Public Apartment Buildings in Ghana.” in *Journal of Engineering, Design and Technology*, vol. 13, issue 2, p. 315–33. https://doi.org/10.1108/JEDT-05-2013-0033.

AHMED, V., TEZEL, A., AZIZ, Z. and SIBLEY, M. (2017). “The Future of Big Data in Facilities Management: Opportunities and Challenges.” in *Facilities*, vol. 35, issue 13/14, p. 725–45. https://doi.org/http://dx.doi.org/10.1108/MRR-09-2015-0216.

BENTO PEREIRA, N., CALEJO RODRIGUES, R. and FERNANDES ROCHA, P. (2016). “Post-Occupancy Evaluation Data Support for Planning and Management of Building Maintenance Plans.” in *Buildings*, vol. 6, issue 4, p. 45. https://doi.org/10.3390/buildings6040045.

BORDASS, B., LEAMAN, A. and RUYSSEVELT, P. (2001). “Assessing Building Performance in Use 5: Conclusions and Implications.” in *Building Research & Information*, vol. 29, issue 2, p. 144–57. https://doi.org/10.1080/09613210010008054.

COOPER, I. (2001). “Post-Occupancy Evaluation - Where Are You?” in *Building Research & Information*, vol. 29, issue 2, p. 158–63. https://doi.org/10.1080/09613210010016820.

COSTA, A.A., LOPES, P.M., ANTUNES, A., CABRAL, I., GRILO, A. and RODRIGUES, F.M. (2015). “3I Buildings: Intelligent, Interactive and Immersive Buildings.” in *Procedia Engineering*, vol. 123, p. 7–14. https://doi.org/10.1016/J.PROENG.2015.10.051.

DEMIAN, P., LIU, Z. and DENG, Z. (2018). “Integration of Building Information Modelling (BIM) and Sensor Technology: A Review of Current Developments and Future Outlooks.” in *CSAE*. https://doi.org/10.1145/3207677.3277991.

EVANS, R., HARYOTT, H., NASTE, N. and JONES, A. (1998). *“The Longterm Costs of Owning and Using Buildings.”* London.

LEAMAN, A., STEVENSON, F. and BORDASS, B. (2010). “Building Evaluation: Practice and Principles.” in *Building Research & Information*, vol. 38, issue 5, p. 564–77. https://doi.org/10.1080/09613218.2010.495217.

LOVINS, A. (1992). "Energy-Efficient Buildings: Institutional Barriers and Opportunities." E Source, Inc., Boulder, CO (United States). https://www.osti.gov/biblio/55563.

MARZOUK, M. and ABDELATY, A. (2014). “BIM-Based Framework for Managing Performance of Subway Stations.” in *Automation in Construction*, vol. 41, p. 70–77. https://doi.org/10.1016/J.AUTCON.2014.02.004.

NATIONAL RESEARCH COUNCIL. (1987). "Post-Occupancy Evaluation Practices in the Building Process: Opportunities for Improvement." Washington, DC: National Academy Press.

PREISER, W.F.E. (2010). “Post-Occupancy Evaluation: How To Make Buildings Work Better.” in *Facilities*, vol. 13, issue 11, p. 19–28. https://doi.org/10.1002/(SICI)1099-1395(199711)10:11<797::AID-PCA951>3.0.CO;2-K.

ROYAL INSTITUTE OF BRITISH ARCHITECTS (RIBA). (1965). *"Handbook Of Architectural Practice and Management."* London: RIBA Publications.

ROYAL INSTITUTE OF BRITISH ARCHITECTS (RIBA) R.S.G. (1991). “A Research Report for the Architectural Profession.” in Duffy, F., Hutton, L., Architectural Knowledge: *The Idea of a Profession.* London: Taylor & Francis.

STRAKA, V. and ALEKSIC, M. (2009). “Post-Occupancy Evaluation. Three Schools from Greater Toronto.” in *PLEA2009 - 26th Conference on Passive and Low Energy Architecture*, no. June:5. https://doi.org/10.1128/AEM.01532-14.

UNDERWOOD, J., and ISIKDAG, U. (2011). “Emerging Technologies for BIM 2.0.” in *Construction Innovation*, vol. 11, issue 3, p. 252–58. https://doi.org/10.1108/14714171111148990.

SHAOMIN, W. and CLEMENTS-CROOME D. (2007). “Ratio of Operating and Maintenance Costs to Initial Costs of Building Services Systems.” in *Cost Engineering*, vol. 49, issue 12, p. 30–33. https://doi.org/10.1016/j.landurbplan.2008.08.004.

ZIMMERMAN, A. and MARTIN, M. (2001). “Post-Occupancy Evaluation: Benefits and Barriers.” in *Building Research and Information*, vol. 29, issue 2, p. 168–74. https://doi.org/10.1080/09613210010016857.

ZIMRING, C.M. and REIZENSTEIN, J.E. (1980). “Post-Occupancy Evaluation: An Overview.” in *Environment and Behaviour*, vol. 12, issue 4, p. 429–50.