55 Post-occupancy Evaluation Parameters in Multi-objective Optimization–Based Design Process

Elie Daher, Sylvain Kubicki, and Annie Guerriero

Abstract

In the design process the main challenge of the designer is to generate an efficient project resulting from different objectives and associated criteria. These objectives are often conflicting and they are related to programmatic requirements, aesthetic, structural, and cost or energy performance. Multi-objective optimization (MOO) can guide the designer towards efficient design solutions. Parametric tools enable integrating MOO techniques and algorithms in 3D modeling environment. They allow the designers to take decisions during the design process. While the optimization tools are considering physical objectives (building energy, performance and daylighting, form generation, structural optimization …) the current applications often lack the evaluation of performance as perceived by occupants, e.g. based on post-occupancy evaluation studies. POE is defined as the evaluation of the building performance by users. Implementing POE in a parametric environment can improve the design and in particular the reorganization of an interior layout space design.

Keywords

Post-occupancy evaluation • Parametric modelling • Simulation • Decision support • Multi-objective optimization

55.1 Post-occupancy Evaluation Research

55.1.1 Definition and State of the Art

Post-occupancy evaluation (POE) is a diagnostic tool and system which allows facility managers to identify and evaluate critical aspects of building performance systematically. This system has been applied to identify problem areas in existing buildings, to test new building prototypes and to develop design guidance and criteria for future facilities [16]. Obviously technical evaluations of a building performance can be conducted, routinely. This can include structural testing, mechanical systems performance checks, lighting checks … However, the POE varies in that since it addresses issues that cannot be easily measured, such as occupant performance, worker satisfaction and productivity [8]. Indeed, users spend significant time in buildings for multiple reasons, and indoor conditions have an influence on their well-being. Poor indoor conditions can affect the productivity and health of the users. Many actors are involved in the life cycle and uses of the buildings, from different points of view and different interests: investors, owners, operators, and the end users occupying the facilities. Recently, different understandings of POE have emerged in the architectural field. These understandings or opinions suggest that POE should cover not only the observation and evaluation of critical aspect of a building but also POE should cover user satisfaction and the impact of the built environment [5]. POE draws on an extensive quantitative and qualitative toolkit: measurements and monitoring, on the one hand, and methods such as walk-throughs, observations and user satisfaction questionnaires on the other [10].

E. Daher (✉) · S. Kubicki · A. Guerriero
Luxembourg Institute of Science and Technology, Esch-sur-alzette, Luxembourg
e-mail: elie.daher@list.lu

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POE carried out on a number of projects of a similar type allows for comparisons between these buildings and helps to highlight and develop their strengths, and addressing their weaknesses and points that need further consideration. However, POE is furthermore helpful to clients' parties in defining the significances and requirements for a new project based on the methodical evaluation of a similar existing facility or project, or even for a new organization of the interior layout of an existing building.

Generally, POE is conducted by using surveys or interviews. With buildings becoming more intelligent and responsive to varying conditions, and thanks to the advent of new technologies (easy-to-integrate wireless solutions), capturing facts inside a building via a set of sensors is being developing significantly today with a real-time data feedback [17]. Measurements of the indoor post-occupancy evaluation are carried out on a number of different factors. Moreover, these sensors make it possible to raise and control eight different categories: "(1) Electricity metering, (2) Gas metering, (3) Air temperature, (4) Mean radiant temperature (5) Indoor air velocity, (6) Relative humidity, (7) Indoor air quality, (8) Occupancy and daylight sensors [1]. However these data do not necessarily represents the feelings by the users and occupants. Sensor-based monitoring supplied to buildings can perform dual roles. First, sensor networks are part of building management systems (facility and energy management), and the second role is that sensors can be of a process intending the validation of the design intent [5].

55.1.2 Benefits of POE

Traditionally, the POE relies on three sources of information: occupants' feedback, bills and Metrics, and measurements and readings. After data collection and analysis, the outputs of the POE can be distinguished in three types of benefits [16].

- Short-term benefits: Identification of problems and solutions in facilities, improvement of space utilization, improvement of the occupant's attitude by their implication in the evaluation process.
- Medium-term benefits: Improvement of the capability of the building to address new change (e.g. organizational change) during its lifecycle, significant costs savings in the building process, etc.
- Long-term benefits: Improvement of building performance, improvement of standards and guidance for building design, etc.

Even if the importance of POE is largely recognized in the academic literature, currently the POE studies are not sufficiently deployed in the construction sector. Professionals are aware of the potential of this evaluation, especially architects that consider in the future that could be a standard mission in the architectural practice. This is an important perspective for the sustainability of building and the whole AECO -Architecture, Engineering, Construction and Operation sector [9]. However, this statement faces the following issues that delayed the POE implementation in the current practices [9, 3]: difficulty to deploy POE on every project, long process required for building quality improvement, high costs of the studies, impacts for professionals in case of negative evaluation of building, availability and heterogeneity of information sources about buildings, engagement of users at long term, uncertainty about the manner the feedback will be used, etc. Today, the digitalization in the AECO sector lets place to new prospects, but the process of POE is not fully supported.

55.1.3 POE and Digitalization

The use of IoT appears in the academic literature as another interesting perspective for POE, because it allows to easily collecting real-time data about the use of the building. Coates and al. [5] are amongst the first researchers that imagined connecting sensors and 3D model to improve the POE data collection. Motawa and al. [15] propose an ontological framework of energy-related information/knowledge which is connected with BIM in order to evaluate the use of energy inside a building with the aim of improving facility management, and occupants comfort based on the sensors data collection. Further, Autodesk Research with the project Dasher [12] has also contributed to this research field with Dasher 360,[1] which connects BIM and the sensors and provides real-time visualization. This type of dashboard contributes to

[1]https://dasher360.com.

refining the understanding of the occupants about how they are interacting with the building, and especially from the energy consumption point of view.

55.2 Parametric Modelling Design Approach

Computational tools are fundamentally shifting architectural design practice to another paradigm [11] and are more and more used in the design process and the generation of forms for contemporary architecture. They are offering new ways to design, evaluate, collaborate and manufacture architecture. Parametric and generative design, simulation, as well as Building Information Modelling, digital fabrication or 3D printing are disruptive technologies implies new practices of design. Computational tools have been developed to help the specialists in the decision making [13] and to accelerate the design of facilities [2]. Over the last 20 years, developments have been made in academic research and practice to design tools and techniques allowing to connect implicit geometrical relations through declared parameters responsible for the geometrical behavior. A well-defined parametric model ensures a control over the geometry without losing the design principles and defined requirements. Constraints can be implemented in the early design phase and can be maintained during the design process. Several tools have been developed in order to support the parametric modelling: Grasshopper a plugin for Rhino, Dynamo a plugin for Revit, Generative component and Houdini.

For decades, architects and designers have been trying to optimize their projects based on criteria such as energy consumption, structural weight, daylight and cost, and more recently, optimization processes in architectural design have been made easier through using computational methods [14]. Several optimization plug-ins were integrated into parametric modelling software allowing numerical simulation and iteration of different solutions [4]. With parametric modelling software the designer is able to evaluate the design iteration in terms of quantitative indicators. Optimization plug-in will also generate different solutions and enable to compare between the quantitative performances related to criteria such as energy, daylight analysis, shadow, view to a landmark, view to the sky, illumination … In order to optimize a problem in parametric modelling tools, a designer has to create a so-called “fitness function” describing the objective to achieve [18]. This process will be linked to the input parameters of the design and the designers should investigate multiple iterations to choose the optimal one.

55.3 Research Objective, Hypothesis and Research Methodology

55.3.1 Research Objectives

Our statement is that the tools enabling optimization in design process are acting on physical parameters that can be integrated as parameters into these computer-based environments, thus providing the simulation of different variables and the optimization of the geometry while following some pre-defined constraints and objectives. However, such tools usually do not enable using “non-physical parameters” [7] such as the people/users evaluations of spaces and projects. In particular the POE can be considered as relying on a set of such non-physical parameters. For dealing with input parameters to define a fitness function of a multi-objective optimization process, the related values do not take into account the user evaluation and satisfaction. The hypothesis is that the current practice with computational aided design tools integrating the MOO methodology could therefore be extended to include user’s post-occupancy satisfaction. To answer this challenge, surveys are usually conducted amongst buildings’ occupants. Such studies enable to evaluate the perceived comfort in a building which may differ from what is thought by the architects in the design phase.

However, POE research appears in the early 60s but it has been facing some limits and has not been adopted by professionals. More recently, with the growth of green buildings which are more exploratory realizations and change profoundly the design patterns, the POE appears as an interesting method to capitalize on each experience [6], especially in UK, where RIBA (Royal Institute of British Architects) encourages the use of POE. Since the comfort of the user is an important factor in the context of new constructions, and which can differ from the intention of the designers, our research focuses on how to integrate the users’ comfort with the 3D visualization systems. Further we aim to link the POE with MOO process through parametric modelling approach to, either develop a new design for the interior layout or the reorganization and adaptation of interior layout in existing building.

55.3.2 Hypothesis

The gap between the real behavior of a designed project and the performance expected by the users justifies the hypothesis to include information related to the post-occupancy evaluation in the digital design process. POE can be used to improve the space layout design in existing building and to be included in the MOO function as a criteria to enhance the design of the working spaces in office buildings. In order to support the requirements of the users in an office building, we consider that design tools should offer additional capacities to include the POE. Taking advance of the POE for either the renovation or design of a facility is useful and important for the life cycle of the project and for the satisfaction of the users.

55.3.3 Research Methodology

The digital evaluation of the building performance can be nowadays easily recorded. In particular information from sensing devices is a way for collecting building behaviour's data, this is easy to achieve since sensing devices have become more and more present in buildings. These sensing devices can track movements within the building. They also allow monitoring the building and collecting information which can be connected to its digital twice, i.e. BIM. Many sensing devices can be integrated into the building related to the indoor air quality, the occupancy, the daylighting or the noise. A comprehensive overview has been provided by Ahmad et al. [1]. Computational and generative design tools are facilitating the integration of optimization techniques into the design processes. These optimization solvers are usually included in the parametric software providing features to search for diversity in solutions. Our research methodology relies on case study implementation to validate a global conceptual framework formulated from the state-of-the-art analysis. The case study applies the approach on the design and reorganization of an office building situated in Luxembourg. The parameters retained for the POE are related to the view, the noise, the daylight and the indoor thermal comfort considered by users as primordial. The tasks realized are related to the reconfiguration of local offices in order to answer the requirements and needs of the occupants in the "Maison de l'Innovation" building (Fig. 55.1).

55.4 Proposed Conceptual Framework

55.4.1 A Conceptual Framework for Including the POE into a Parametric Approach

To address the issues raised in the state of art we consider a conceptual framework representing the design situation with: (1) processes and (2) actors involved, and the (3) digital technologies enabling to provide a parametric modeling environment. The framework thus deals with the (A) design process and situation presented, for each situation, the (B) data collection should be performed related to the physical parameters, later, the integration and (C) digitalization of the collected data, and the technologies associated to perform a MOO process (see Fig. 55.2). In the context of this article, the innovation in such a MOO is by including the POE items as a set of parameters in the design process (yellow box).

However, it is important to note that the conceptual framework proposed is grounded in a wider theoretical paradigm developed in a context of a PhD and related to the participation of users on the design of their products. Indeed, taking into account the POE to design new interior layout of an office building is considered as a type of participation involving the users in the new design.

In our use case, the designer is considered as the facility manager responsible for the reorganization of the interior layout. The users, themselves, are the occupants of the building who answered the surveys.

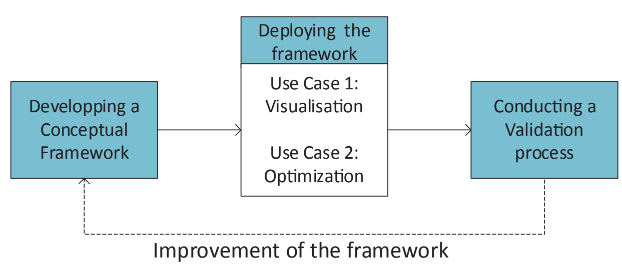

Fig. 55.1 The methodology

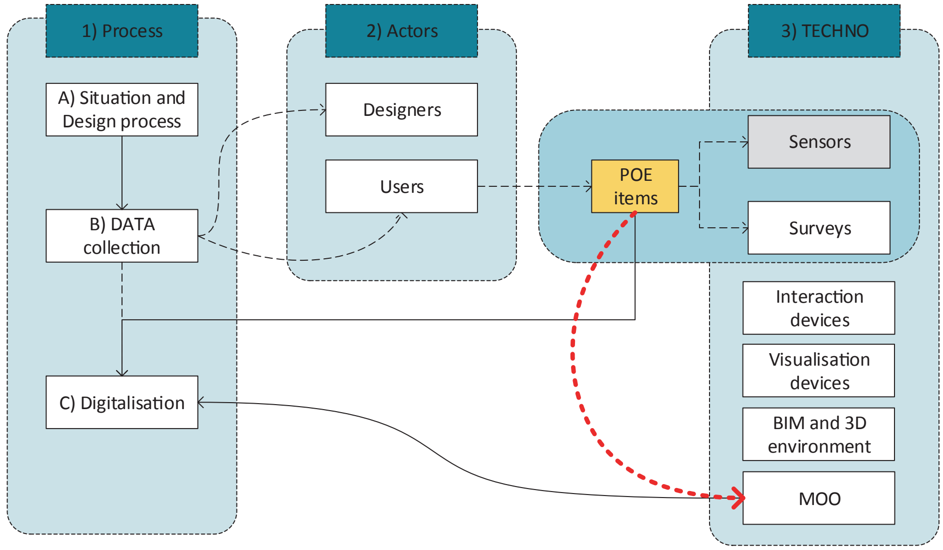

Fig. 55.2 The proposed conceptual framework

55.4.2 Application to POE-Based Floorplan Layout Design

As our interest in parametric approach relies mainly on its application in design processes, it is important to carefully choose the software and devices to be used. The choice to implement the software and devices in our framework was made according to the accessibility, functionality and ease to use. These tools and technologies are related to the (1) visualization, (2) 3D environment and (3) sensing technologies. For the visualization, these interaction technologies were linked to virtual environment allowing the visualization of the 3D and the 3D simulation in a VR/AR environment. The use of these technologies produces a simple understanding of the design model proposed and ensure a better understanding of the proposed solutions.

The use of parametric modelling tools is justified by their ability to easily manipulate algorithms based on visual components and to create dependency between the model and the input parameters. The modification of input parameters will result in real-time modification of the 3D geometry. As for BIM (Building Information Modelling) tools, it was important to extract the semantic information of the spaces and to attribute the POE result to each space as well as to understand the relation between the space and the POE result. This relation between both space and POE helps in identifying the reason of the resulting perception of users about the spaces, and to record the important points to take into account in future development of design. These values should then be compared with the POE conducted via surveys. After the identification of relation between the two sensing approaches (human and physical), each indicator would be translated into input parameter for the model. Optimization techniques integrated into the parametric modelling tools will be acting on these input parameters to search for optimal solutions. These parameters will be weighted according to their importance. The weight for each input will be concluded from the objective data recorded through sensors and human evaluation collected by surveys. These optimization techniques will integrate in addition as inputs the Post-Occupancy evaluation data enabling the evaluation and analysis of different solutions generated by our system.

55.4.3 First Prototype Implementing the Approach

The purpose of this prototype (see Fig. 55.3.) is to visualize the answers given by the users in a 3D environment and to be able to connect the spaces occupied by employees to the average answer of the POE. Based on a 3D BIM model for the "Maison de l'Innovation" (MIN), each space was connected to the average evaluation of the POE survey exploited in Grasshopper with a connection to the data in an excel sheet. The POE survey answered by users covers different items of comfort. These items were related to sound, light, natural daylight, view to the outside, equipment (related to the furniture of the offices), and indoor air quality (for summer and winter). The evaluation of each item was scaled from 0 to 4. In this

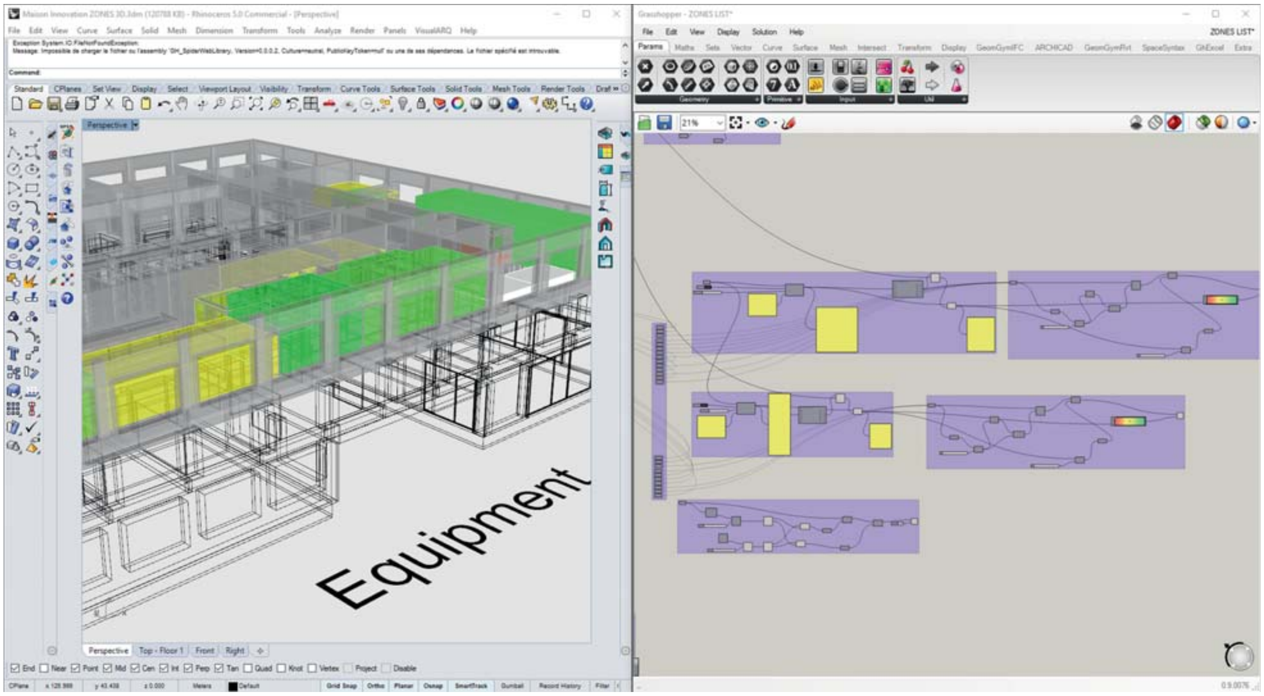

Fig. 55.3 The first prototype showing the visualization of the post-occupancy evaluation item for equipment

figure, the POE item shown is related to the equipment, where each space is showing the average of the result of the evaluation with a color code indicating the level of evaluation.

Thanks to the IFC format, the related spaces were exported and implemented in the Grasshopper environment. The objective of this first prototype is to use the parametric model to better understand the survey according to answers, and to interpret the results in a more informed manner. The visualization of the POE data in each space allowed us to rethink new layouts to answer some of the issues raised by the user's evaluations. Another interest in this workflow is the link created between the BIM environment and the parametric design environment.

55.4.4 Second Prototype

The second prototype (see Fig. 55.4) proposes to study the reconfiguration of the interior layout taking into consideration not only physical parameters but also human collected parameters, and in particular the POE data set. In this prototype we only considered the values of the sound comfort and the view. These evaluations have been transformed into input parameters and integrated into the parametric models with weighting criteria according to the importance of each indicator as shown in the framework. With integrated optimization plugins in the parametric tools, we are able to iterate different solutions based on our input. A few combinations were defined in this second prototype, and the work is ongoing to develop optimization functions that are more complete.

55.5 Validation

The proposed prototypes present opportunities for further development. However, even though the limits of the prototypes are identified, the validation of the hypothesis and the associated framework is conducted at three levels.

First, the development of the first prototype demonstrated that parametric modelling can be used for the visualization of the information concerning the POE, thus facilitating the understanding of the information and data represented.

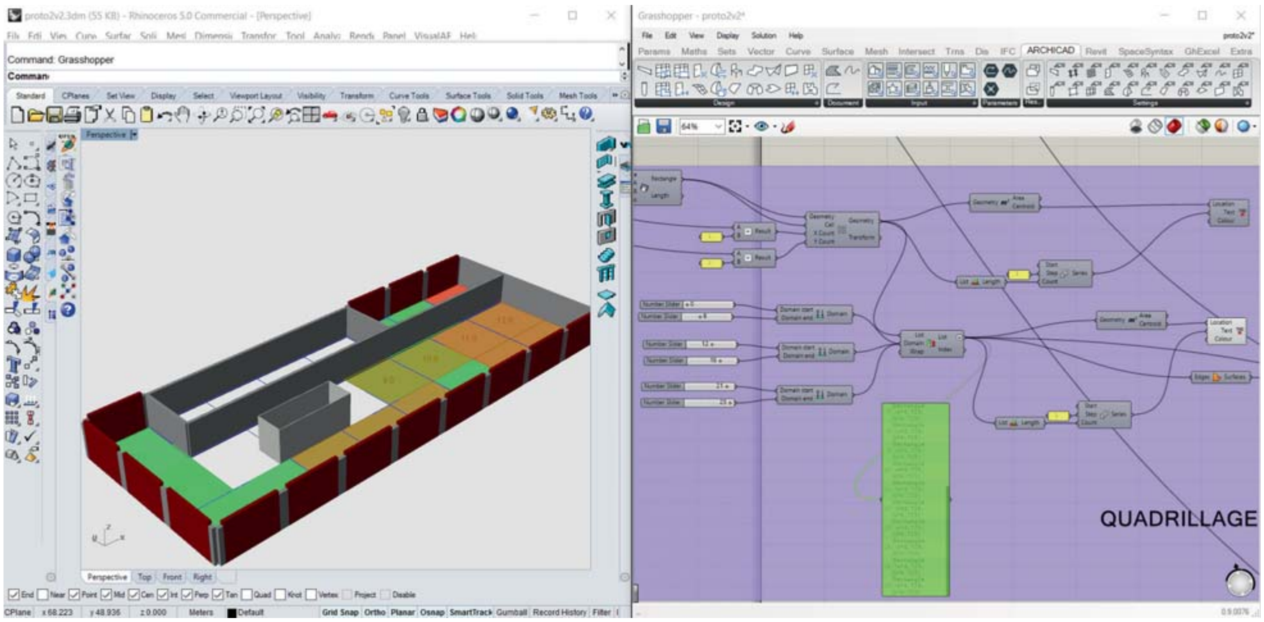

Fig. 55.4 The second prototype developed according to the users' post-occupancy evaluation

Second, the development of the second prototype demonstrated that the optimization techniques integrated in such parametric tools make sense, and can be based on the POE as input parameters, thus introducing "non-physical parameters" into the model.

In a third phase, both prototypes were confronted to the occupants from the concerned building. This development enabled for occupants to first visualize the results of their evaluations. Occupants also showed an interest in the second prototype which helps in the generation of workspace layout taking into account their own evaluations.

55.6 Discussion and Conclusion

This ongoing research aims to demonstrate the interest of taking into account the POE in the design process. Indeed, the simulation tools usually available at design time have shown a gap between the predicted results of simulations and the real perception and evaluation of the users. To fill that gap, this research aims to develop a framework where the POE items would be integrated as new parameters that can be computed towards discovery of design solutions. These new parameters related to the POE can be presented as non-physical parameters since they are dealing with the human evaluation and in most cases to unpredicted evaluations. By introducing this type of parameters, the solution presented at the design stage would ensure that the gap between simulation tools and human evaluation is filled, or reduced. Users can evaluate the spaces they occupy and the way they feel their performance. The research presented in this paper proposes a prototype to visualize the POE result in a 3D parametric model. The results obtained are then evaluated to better understand them and to be transformed into parameters as another input in the parametric model before the reconfiguration of the new layout spaces. Further evaluations with the occupants shall be undertaken to test the efficiency of the prototype. In a future version, we expect that physical indicators about the building will be collected by sensors placed in the different spaces of the building. Intersecting the questionnaires collected from the occupants with the physical data recorded by such sensing devices is a promising method to improve the quality of future buildings. Although this framework focuses on the buildings, our future developments will also address the POE as parameters at the area/neighbor level.

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