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Performance Evaluation of Smart Home: A systematic analysis of literature

Nascimento D R[1], Ensslin S R[2], Gumz J[3]

Abstract The usage of smart home is an emergent matter in the construction industry and demands the builders a search for resource optimization to create strategies and competitive advantages and, therefore, supply for the users' needs. To facilitate this resource optimization, the performance evaluation tools help deciders on your decision-making. In that context, this article's goal is to identify the characteristics of studies in the area of performance evaluation of smart home system. We used the ProKnow-C as the instrument of methodological intervention that guided the 30-article selection from the Scopus and Web of Science database. Based on the bibliographic portfolio selected: (i) the bibliometrics analysis allowed the finding of the existence of discussions of emergent characteristics in temporal periods (2005-2009, 2010-2014 and 2015-2019) (ii) the systemic analysis evinced that the descriptive and normative scientific approaches guide the development of 86% of researches from BP, with coherent activities of measurement and without the application and management of a performance evaluation of smart home system.

Keywords: Performance Evaluation; Smart Home; Systematic Analysis.

1 Introduction

The increasing use of communication and informational technology supported by the Internet of Things (IoT) granted the development of smart home (Langhammer and Kays, 2012; Lin *et al.*, 2016; Kang, Lin and Zhang, 2018; Fettermann *et al.*, 2020a). In the construction branch, smart buildings arose as a competitive advantage in the optimaztion of energy resources to constructors as well as a differentiation in terms of comfort to users, by the implementation of intelligence in buildings (Chen, 2006; Katz and Skopek, 2009; Fettermann *et al.*, 2020b). This competitive advantage awakened interest in builders and residence users in search of comfort and well-being by implementation of new technology.

Organizations, when introducing the smart home concept in their strategies, realized the need to identify means of evaluating the performance of their services and products so that their differential would get to the client and their resources would be optimized. In order to facilitate the strategies implementation and improve company performance, the performance evaluation systems are constantly recommended (Melnyk *et al*., 2013). The smart home nature of services and products generates the need of monitoring during the residence use, which becomes more efficient with diagnosis obtained by means of the Performance Evaluation (PE). Companies are more and more under pressure to create value to their stakeholders. Due to that, the practices of PE might contribute to this task (Franco-Santos, Lucianetti and Bourne, 2012; Fettermann, Echeveste and Tortorella, 2017).

Practices of evaluation and performance Management are common in all sectors, so much in the industry as in the commerce (Bititci *et al.*, 2012). Performance evaluation is a re-search theme that permeates several knowledge areas, including the emergent ones. Facing this context, the following research question arises: How the performance evaluation is presented in relation to smart home in the current literature? The goal of this work is to identify characteristics of studies in the area of performance evaluation of smart home,

[1]Débora Rosa Nascimento (✉e-mail: debora.nascimento@ifmg.edu.br)
Department of Production Engineering. Federal University of Santa Catarina. Campus Universitário Reitor João Davi Ferreira Lima, S/S. 88040-900, Florianopólis.

[2]Sandra Rolim Ensslin (e-mail: sensslin@gmail.com)
Department of Production Engineering. Federal University of Santa Catarina. Campus Universitário Reitor João Davi Ferreira Lima, S/S. 88040-900, Florianopólis.

[3]Jonathan Gumz (e-mail : jonathan.gumz@gmail.com)
Department of Production Engineering. Federal University of Santa Catarina. Campus Universitário Reitor João Davi Ferreira Lima, S/S. 88040-900, Florianopólis.

by means of a literature fragment, obtained by searching in two specified database and in a determined period, which delimits this work. The tool of intervention used to achieve this goal is the ProKnow-C (Lacerda, Ensslin and Ensslin, 2012; Dutra *et al.*, 2015; Thiel, Ensslin and Ensslin, 2017).

The contribution of this article can be noticed by the academic area and by its practical applications. To the academia, this article enriches the current literature by means of a systematic and specific review about smart home in the light of the performance evaluation. Enrichment that deals with the contributions of performance evaluation applied to smart home. Identifying which methods and tools have already been in use to evaluate and improve the performance of technology and its interactions to the environment and to the user in a smart home. To practical application, the companies related to smart home technology, be they constructors, information technology companies, automation companies, among others, might obtain strategic targeting in this work in order to improve the performance of a smart home.

2 Methods

This work used the Knowledge Development Process-Constructivist, (ProKnow-C), as methodological intervention instrument (Staedele, Ensslin and Forcellini, 2019). This tool is guided by the constructivist approach that allows it to generate knowledge about a research theme based on the selected literature. This characteristic makes the instrument adequate to achieve the goal of this work. In general, the stages of (i) selection of the bibliographic portfolio, (ii) bibliometrics analysis, (iii) systemic analysis and (iv) research question. All these stages are com-posed by substages. In this work, the four of them were developed.

2.1 Procedures of Data Collection: Selection of the Bibliographic Portfolio (BP)

Figure 1 presents the summary of the selection of the Bibliographic Portfolio (BP) stage. In sequence, the procedures made in the selection of raw-article bank and data base filtering substages are described (Lacerda, Ensslin and Ensslin, 2012; Dutra *et al.*, 2015; Thiel, Ensslin and Ensslin, 2017; Staedele, Ensslin and Forcellini, 2019).

To the bank selection of raw articles is necessary to define the thematic cores of research. As the goal of this article is to identify the characteristics in the studies of the area of performance evaluation of smart home there are two cores: performance evaluation and smart home. To performance evaluation, we defined the following key words: performance evaluation, performance measurement, performance assessment, performance management, performance metrics, performance indicator and performance appraisal. To the smart home core, the terms defined as key words were smart home, smart house, home automation networks, internet of things, IoT, smart building, smart household, intelligent building, intelligent house, intelligent home and HANs. The databases used to research were Scopus and Web of Science. Still, only publications in scientific periodicals, in English and published until 2020, were considered. The research with the key words was done in the fields: title, abstract and key words - of published articles in the database. The period of execution of the research in the bases was from October 17th, 2019 to October 23rd, 2019. It was found a total of 1,253 articles with the base on the delimitations of this research. The test of key words adherence was done, and these remained the same, ending in 1,253 articles in the selected raw article bank.

The substage “filtering of the article bank” had its start with 1,253 articles. All of them were exported to the EndNote software and 290 doubled publications were excluded directly by the software and 187 publications in conferences, books and chapters of books, obtaining, in the end of this first filtering, 776 articles. These were examined according to its title, and, in the cases where the titles of the articles were clearly misaligned, 671 were deleted by not contributing to this research, 105 articles remaining.

It is necessary the identification of the scientific representativeness by means of the number of quotations in each article. In this research, among the 105 articles, the 38 best-quoted ones represented 91.5% of the total number of quotes, forming a scientific relevant repository; and the 67 remaining articles presented less than 10 quotes, making a repository with potentially relevant articles. Among the 38 non-repeated articles, with aligned title and scientific acknowledgment, 22 of them had the abstract aligned with the theme. A total of 85 authors, forming the Bank of Authors (BA), wrote these 22 articles. To guarantee the scientific representativeness, we used a repository of 67 non-repeated articles, with aligned title and potential scientific acknowledgment for filtering. The most recent articles (published in 2017, 2018 and 2019/2020)

were separated from this group: 55 articles. From the remaining ones, the articles in each at least one of the authors was integrant of the BA were chosen, and in that case, only one article was. From 56 selected articles with potential scientific relevance, eight presented an abstract aligned with the theme.

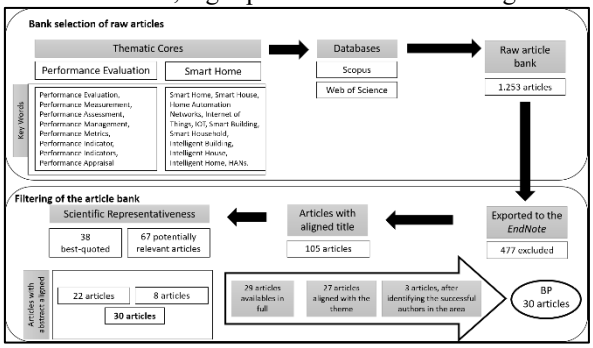

Fig. 1 A Selection of BP, according to ProKnow-C

At the end of this filtering, we obtained 30 non-repeated articles, with aligned title and scientific acknowledgement. Among these 30 articles, 29 were available in full, but two were unaligned with the theme. Therefore, we selected 27 articles to compose the final Bibliographic Portfolio (BP). After identifying the successful authors in the area, we added three more articles to the final BP. In that way, the final BP was composed of 30 articles.

2.2 Procedures of Data Analysis

Among the 30 articles in the BP of the smart home considering the performance evaluation, three are theoretical studies that present concepts and definitions. There-fore, based in the other 27 articles, it was possible to have a diagnosis by the systemic analysis guided by the theoretical affiliation of Ensslin (Ensslin *et al.*, 2013). The process of performance evaluation is conducted through activities that identify, organize, and measure ordinally and cardinally the key performance factors, which allow the decision maker to understand the consequences of actions. From this theoretical affiliation, derive six branches – Approach, Singularity, Identification of values and preferences of decision makers, Measurement, Integration and Management (Ensslin *et al.*, 2013) – from which the 27 empirical articles will be evaluated.

3 Theoretical Reference

3.1 Smart Home

Thirty articles, published between the years of 2005 and 2019, compose the BP. The bibliometrics analysis allowed the finding of the existence of discussions of emergent characteristics in temporal periods. In each of the moments, some characteristics show up by being discussed in more than one article, that is, different authors discussed the same characteristic in the same window of time. Based on these characteristics, the names for each moment of the subject evolution were given (Figure 2).

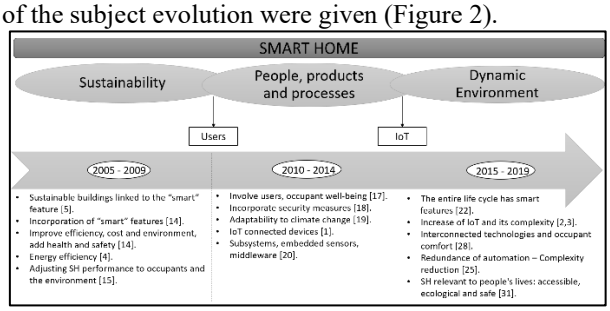

Fig. 2 Evolution of Smart Home throughout the years, based on the BP

Sustainability of Smart Home (2005 to 2009)

The word 'smart' was used for the first time to describe buildings in the United States in the beginning of the 1980s (Wong, Li and Wang, 2005). With the advance of technology, mainly the information and communication ones, the smart features began to arise, starting from the 21st century, in the studies and

market of construction industry (Ochoa and Capeluto, 2008). Katz and Skopek (2009) affirm that, in the decades 1990 and 2000, there was a relevant debate about the concept for smart building, and the final impression that stayed from these efforts is that a building of such a kind cannot be only a definition, because there is a multiplicity of areas involved. Inserted in this context of smart home discussion by several different areas, around 2008, a rising interest by the part of architects and entrepreneurs was observed, in including intelligence in buildings, as a way of achieving buildings with energetic efficiency that fulfill strict energy codes and national marks of reduction in dangerous emissions (Ochoa and Capeluto, 2008). Therefore, some authors, used definitions of smart home focused on the sustainability approach to guide their studies about the energetic efficiency in buildings (Chen, 2006). Studies that define performance indicators also used this sustainability approach (Wong, Li and Lai, 2008). Beyond the studies that focus on more specific smart home issues, like Ochoa and Capeluto's study (Ochoa and Capeluto, 2008) that analyses the smart façades as support to the energetic efficiency in buildings.

People, Products and Processes of Smart Home (2010 to 2014)

In the sense of searching a definition for smart home, in this second moment of evolution, the researches started to adopt concepts that involved people, products and processes, such as in the work of Alawaer and Clements-Croome (Alawaer and Clements-Croome, 2010). The focus on people remains present on the approach of smart home processes, such as the implementation of security (Sun *et al.*, 2013) and the adaptation of smart home systems to the climate changes (Vardakas, Zorba and Verikoukis, 2014). The products inserted on the context of smart home are related to the sensors and to the objects connected to IoT (Langhammer and Kays, 2012) that develop, in parallel, the systems and subsystems of home automation (Perumal, Ramli and Leong, 2010). This technological approach was used to develop climbable technology of home automation and smart home, using Internet (Sun *et al.*, 2013). This is a tendency by the interoperability of smart systems in artificial constructions (Perumal, Ramli and Leong, 2010). Despite these tendencies, in fact, there is no pattern in the systems of home automation; the studies differ in their characteristics and present specific advantages and disadvantages (Langhammer and Kays, 2012). Works with the focus on subsystems of smart buildings grew due to the combination of embedded systems of high and low costs, plus the emergence of high capacity infrastructure of communication, plus the Internet (Perumal, Ramli and Leong, 2010). Even with low costs and high performance of home automation systems, there is still no bigger diffusion of smart home in practice (Langhammer and Kays, 2012), but it is observed an increase on the importance of smart environments with smart home (Arndt *et al.*, 2013).

Dynamic Environment (2015 to 2019)

To create such a dynamic environment, it is necessary for the smart features to be incorporated in all phases of a building life cycle (Arditi, Mangano and De Marco, 2015). This aspect of construction leads to an increase in the use of IoT technology and if the amount of objects connected to IoT increases, so does the complexity of smart systems (Lin *et al.*, 2016; Orsino *et al.*, 2016; Dumanli *et al.*, 2017; Shirehjini and Semsar, 2017; Song *et al.*, 2017; Kang, Lin and Zhang, 2018). Several studies characterizes this fact (e.g. Fahad, Khan and Rajarajan, 2015) that shows the use of telemedicine in smart home, allowing the continuous monitoring of people that live alone. Another study analyzes wireless localization with focus on IoT (Lin *et al.*, 2016). Dumanli *et al.* (2017) cite the advances on the detection technology as a solution to the modern health and wearable technologies to monitoring of the health and well-being of the smart home user. These studies search to develop interconnected technologies and the comfort of occupants, besides the sustainability (Ghaffarianhoseini *et al.*, 2016). Despite the sustainability being the most present approach on discussion in the first moment of this analysis evolution, it continues in the posterior studies, as in the preoccupation with energetic efficiency in wireless technologies (Orsino *et al.*, 2016). The same happens with the maintenance of the preoccupation with characteristics in the second moment, as in the smart building concept Arditi uses, which contains aspects of energetic costs (Arditi, Mangano and De Marco, 2015). That is, despite the efforts towards technology, the user remains in the smart home studies, a fact that is also presented on the work of the development of an adequate interface to increase the trust of the smart home user (Shirehjini and Semsar, 2017). Facing the scenario of evolution and fast diffusion of technologies turned to smart home environment (Ghayvat, Mukhopadhyay and Gui, 2016), some authors affirm that it happens now, an excess of automation created by problems like loss of control, environment complexity and lack of user interfaces suitable to daily smart devices (Shirehjini and Semsar, 2017), being

necessary the reduction of the complexity that this excess creates (Gunawan *et al.*, 2018). Many researchers and developers glimpse, project and develop apps to change physical environments into smart spaces and improve the use of the smart home, facilitating its broad implementation (Gunawan *et al.*, 2018). In this way, smart home can become relevant to people's lives in an accessible, ecological and safe way (Tiwari, Sewaiwar and Chung, 2017).

3.2 Smart Home and Performance Evaluation System

With the main of comprehending the theme in the light of performance evaluation area, it is necessary to make the central notion of this area of knowledge explicit. The Performance Evaluation System contemplates two subsystems: performance measurement and performance management (Lebas, 1995; Melnyk *et al*., 2013) which can also be called Performance Measurement and Management System. (PMMS). This holistic approach of Performance Evaluation sustains the notion that these two subsystems are complementary (Lebas, 1995; Ensslin *et al.*, 2013; Melnyk *et al*., 2013). The measurement serves as support to the management that needs the information and diagnosis to guide the actions to be planned and taken.

Based on the analysis of the BP articles, we verified the alignment of the studies content with the functions of the two Performance Evaluation subsystems. Figure 3 summarizes this alignment. Following it, we detailed this alignment first introducing the notions of PE supported by theorists of the area and then the studies of the BP.

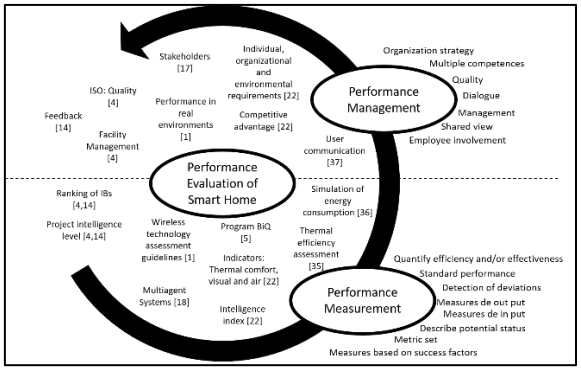

Fig. 3 Alignment of the theme smart home with the Performance Evaluation subsystems

Studies about Performance Evaluation of Smart Home present these characteristics as a study about the thermal efficiency of smart home (Sakuma and Nishi, 2019); the usage of the Program BiQ as reference to the development of a measurement process (Katz and Skopek, 2009) and the usage of a multi agent system composed by a group of metrics to performance measurement of smart home (Sun *et al.*, 2013). Measures based on critical/successful factors, which describe a potential status/status quo, of detours detection, of output and input are measures of the performance measurement process (Lebas, 1995; Neely, Gregory and Platts, 1995; Ensslin, Dutra and Ensslin, 2000). The system of classification exists to rank the smart buildings based on measures of intelligence and sustainability (Chen *et al.*, 2006), considered factors of success in the market of smart home. The index of intelligence presented on the work of Arditi (Arditi, Mangano and De Marco, 2015) is a measure of output in the performance measurement process. The simulation is another tool to evaluate the smart home, as in the case that the simulation was used to evaluate the energy consumption of a home in order to detect possible detours in the consumption expected by users (Kemel and Memari, 2017).

The performance management of smart home may be represented using PE as a competitive advantage to builders (Arditi, Mangano and De Marco, 2015), evidencing the use of organizational strategy in the PE (Melnyk *et al*., 2013). Besides this feature, the performance management can be identified by the preoccupation with the use of multiple competences, dialogue, quality, management, shared vision and envelopment of contributors (Lebas, 1995). In the smart home field, the feedback (Wong, Li and Wang, 2005) and the installation management (Chen *et al.*, 2006) were preoccupations of the PE in the first studies about the theme. In this initial period, the use of the quality terms by ISO was done to guide the management of maintenance of smart buildings (Chen *et al.*, 2006). Afterwards, stakeholders that helped in the

determination of indicators and their relevance (Alawaer and Clements-Croome, 2010) developed the shared vision of performance management. The tendency observed in the last studies to seek focus on the users and owners between the processes of evaluation and the user (Amin *et al.*, 2017), enabling the dialogue among those involved in the performance management.

4 Results

In the BP diagnosis in relation to lens 1, approach, the descriptive and normative scientific approaches guide the developments of the researches in the BP with 86% of articles presented in that way. There was no article with a constructivist approach. By being guided by descriptive and normative approaches, most of the researches is from generic nature (71%); however, some did not present harmony (8 articles) by using normative and descriptive approaches to application in some specific context, in only one company, to home performance evaluation.

The diagnosis of lens 2 exhibit the singularity that aims to identify if the model/tool built to evaluate certain context recognizes the specificity of this context and incorporates the demands of decision makers. In the analyzed BP, most of the articles do not identify who are the decision makers (61%), keeping a pattern with the descriptive and normative approaches in relation to the smart home theme. Only one article built a methodology of performance evaluation to be applied in a specific context. In that way, it identifies that the articles of the BP did not build their models/tools in a singular or unique way (89%).

The BP diagnosis in relation to Lens 3 identify the values and preferences. How the perception of the decision maker is taken into account to identify the features in models/tools of the performance evaluation and identify in this process the existence of preoccupation with the expansion of the decision maker's knowledge, by means of the lens 3 in the systemic analysis. The majority (71% of the articles) does not recognize values and preferences of decision makers. Therefore, the diagnosis in relation to lens 3 of the systemic analysis is that the studied BP do not present legit behavior of the measures taken in the empirical studies to 'eyes' of who uses these tools.

The BP diagnosis in relation to lens 4 show the measurement. The articles in BP contemplate the activity of measurement of the goals identified as important to the organization, by means of the fourth lens of the systemic analysis. We can say that the BP presents measurement activities (93% of the articles), except for one article; the remaining ones identify the type of scale. The performance evaluation of smart home normally occurs by means of the application and/or adaption of norms and patters of IoT specific technology. To this kind of application, the performance indicators are, mostly, quantitative scales of reason type. Simple mathematical operations were used to calculate the indicators, and averages and bar graphs to the comparison. Therefore, under the fourth Lens, the BP presents a diagnosis of compatibility of measurement activities.

The lens 5, integration, approach the scales integration based on the decision maker's perception under a holistic vision of performance or only the final result. Even though the BP shows articles with measurement activities, it does not present integration of the calculated indicators. The presentation of indicator occurs as a way of comparison to the Performance Evaluation. In only eight articles of the BP, the integration of the articles is identified, and this integration occurs in a well-distributed way without presenting any tendency of characteristic more common to the Performance Evaluation of Smart Home. The BP contemplates articles with integration under a holistic vision and other articles with only an overall result. Most of them makes the integration without the participation of decision makers and of descriptive, graphic and cardinal ways.

The systemic analysis under the sixth lens, management, observes if the models enable the monitoring and improvement of performance by means of the identification of the current situation diagnosis and the availability of process to create actions of improvement. In this perspective, the article developed some activities in the direction of performance evaluation management. In the moment, the diagnosis is delivered, a feedback is presented showing the strengths and weaknesses. Besides this diagnosis, they offer improvement to building performance by consultancies. The program uses the level of intelligence of each building to make a comparison between buildings and, therefore, creates a ranking.

From the systemic analysis, then, the articles that compose the BP of this study are guided by the descriptive and normative scientific approaches with the presence of coherent measurement activities; however, there is not a management of this performance evaluation of smart home. Therefore, we identify a possibility of

studies: Why aren't there articles that do not show indicators management? Would this be a promising area of investigation? Would it be a bottleneck in the processes of smart home?

5 Final considerations

The concepts and definitions of Smart Home originated from the studies of intelligent buildings around the beginning of the year 2000, indicating it to be an emergent theme. The evolution of the studies in the area under the light of the performance evaluation does not appear in a linear way, indicating studies that are focused on the standardization of performance evaluation methods in parallel with studies focused on demonstrating the importance of creating an evaluation systems to each specific case. However, it is possible to identify features, in these studies, of performance management and performance measurement.

This work allowed us to identify the features of the studies in the area of performance evaluation of smart home, by means of a fragment of literature. For such, we selected a BP composed by 30 articles, published between the years of 2005 to 2019. In general lines, the studies analysis pointed the descriptive and normative scientific approaches guide the development of 86% of the BP researches, possibly because of the type of technology needed to smart home development; however, to the light of the adopted theoretical affiliation we stated that the BP studied do not show legit behavior of the used measures to 'eyes' of who uses the PE tools. These technologies are based in standards and protocol that enable the development of coherent measurement activities by means of indicator calculation, comparative description of results and graphics. Still in this BP, we observed the lack of studies that discussed and showed methods to the management of performance evaluation systems.

Additionally, we stated that the lack of empirical studies that demonstrate the management of performance indicator could point a direction to new studies in the thematic area. Studies that investigate the motives of this absence and identify the importance of performance evaluation management can become essential to the academia as well as to the construction industry. The vision about this topic evolution was obtained by means of a fragment extracted from the literature with specific conditions of data collection. This situation limits the present study.

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