Implementing a PSS approach to improve maintenance operations of facility equipment

Nicolas Haber*, Mario Fargnoli, Mara Lombardi* and Massimo Tronci***
* Sapienza University of Rome, Rome, Italy
** Universitas Mercatorum, Rome, Italy
njhaber@gmail.com, mario.fargnoli@unimercatorum.it, mara.lombardi@uniroma1.it; massimo.tronci@uniroma1.it

Abstract

Economies based on product-centric models have considerably shifted towards service-oriented solutions such as Product-Service Systems (PSSs). Facilities and properties are no exception where maintenance operations and activities play an essential role in their management. In this context, several tools are used to enhance the management performance of those facilities. Nevertheless, only a few studies have investigated these topics while contemplating a shift from product-centered approaches to service-based models. The following study adopts a Building-Information Modeling (BIM) approach in a PSS environment to enhance the maintenance operations of facility-related equipment. In detail, a maintenance organization and management framework is constructed through the implementation of PSS-BIM integration. The study concerns the elevators of an existing structure where the framework is applied bringing forth the benefits that can be achieved notably in terms of reduced downtime, lower maintenance costs, and higher customer satisfaction. Despite the limitations of the intervention, the approach can be deemed as a reliable first step towards a more thorough PSS implementation in this sector.

Keywords

Product-Service System (PSS), maintenance management, facility management, facility equipment, Industry 4.0

1. Introduction

Through recent years, manufacturers and researchers alike have stressed the need to improve the manufacturing and management of products. Most notably, they pointed out the need to address the product's entire life cycle and employ strategies enabling this approach (Tukker 2015). The product should be comprehensively optimized: the design, prototyping, validation, market launch, use and recovery must be considered throughout the product's lifecycle to enhance its environmental performance and to have a positive effect on the manufacturer's operations (Ulaga 2011). One of the most vital aspects to consider is the use phase of the product where the balance can easily towards the negative side of the scale if not handled properly (Takata et al. 2004; Haber et al. 2018).

The transition towards Product-Service Systems (PSSs) has been highlighted as one of the most prominent approaches to improve the product's performance and value through the entirety of its lifecycle stages. Application and use-oriented systems are no exception since the functioning of the product relies heavily on the effective planning and execution of its related maintenance operations (Wang et al. 2020). Products and equipment set up in buildings and facilities (i.e., communication systems, elevators, metal detectors, etc.) are not exempted (Fargnoli et al. 2019): the involvement of several stakeholders from one side, and the positioning in regulated markets on the other render the application of PSSs an encouraging answer. In detail, the need to balance between the various needs of different stakeholders combined with the fact that maintenance operations are supplied by the equipment manufacturer can be fulfilled via a PSS implementation (Vezzoli et al. 2015; Fargnoli et al. 2019). Furthermore, modern technologies such as distant servers, remote surveillance, and monitoring schemes and the infamous "Industry 4.0" (Bortoluzzi et al. 2020) can take the benefits of a PSS to the next level in a facility/building equipment environment.

Numerous studies investigated a more extended servitization of the building equipment field: a design framework for personalized PSS solutions was brought forth by Song and Sakao (2018), Van Ostaeyen et al. (2013) explicated the advantages that a manufacturer can have by means of different PSS solutions, Ferreira Junior et al. (2022) illustrated the benefits of a PSS in handling the maintenance operations at a manufacturing plant, Cortesi et al. (2010) brought to light the positive environmental impact that a PSS can achieve using a case study at an elevator manufacturer as an example, and Dalenogare et al. (2019) shed light on the improved performance of maintenance activities when a PSS is in use compared to a non-PSS application.

Furthermore, researchers addressed the enhancement of facility management by means of integrating digital and software-based technologies via Building Information Modeling (BIM). Bynum et al. (2013) and Kensek (2014) emphasized the role of BIM in improving maintenance operations leading to an overall better facility management performance (Hernandez et al. 2018; Wong et al. 2018). Nevertheless, despite the numerous advantages of PSS and Information Technology (IT) tools such as BIM, their integration and joint implementation is severely lacking and further research supporting firms and facilities is needed to better address the hidden opportunities that an advanced servitization model can offer (Bertoni and Larsson 2017; Ardolino et al. 2018). Another review study (Acerbi et al. 2021) stressed the fact that manufacturers should adopt digital tools to collect data regarding consumers' behaviors and product conditions, during the usage phase, to ensure the provision of tailored services. This can improve the maintenance operations of the functionalities of the product as well as support future design improvements. Consequently, the following research seeks to answer the following Research Questions (RQs):

RQ1. How can PSSs be combined with digital tools for a better overall performance?

RQ2. Can a digitally augmented PSS improve the management of facilities, in particular the maintenance activities?

The remainder of this paper is articulated as follows: section 2 provides a literature review for the study while bringing out the motivations of this research. Section 3 portrays the research approach that is tested at an elevator manufacturer in section 4. The obtained results are depicted and discussed in section 5 whereas section 6 concludes the article.

2. Literature review and research motivations

2.1 Product-Service Systems

With increasing market competition and growing environmental concerns, modern businesses are adopting more and more often PSSs as a means of meeting their triple bottom line: economic and financial success, increased customer satisfaction and hence customer loyalty, and environmental performance (Haber and Fargnoli 2017a). These systems are based on supplying the customer with complete solutions based on functional outcomes as a substitute for conventional product transactions and sales. PSSs combine products and services to achieve what the tangible commodity cannot do or augment it with additional advantages. Moreover, such approaches enable the solution providers to address customer requirements in a more innovative and effective manner to achieve their set out goals (Mont, 2002; Beuren et al., 2013). The customer, i.e., the solution receiver, obtains an outcome customized to their specific needs through the integrated services while the solution provider, the PSS supplier, gains the customer's trust and loyalty. Thus, the market and customer concerns are addressed.

Regarding the environment, the physical products are better managed, as the manufacturer or supplier would retain control and operate it in an adequate manner that reduces the risks of misuse by the customer. One of the key outcomes of this approach is the optimized use of resources, an improved maintenance strategy, and facilitation regarding the End-Of-Life (EoL) stages, e.g., refurbishment, reconditioning, etc. Consequently, the outputs of one manufacturing cycle are the inputs of another manufacturing cycle (Tran and Park 2015). The literature most commonly classifies PSSs under three main models (Tukker, 2004):

- Product-Oriented (PO): the product's ownership is moved from the PSS provider to the PSS receiver in addition to complementary services that raise the global value of the product (i.e., warranty, maintenance, etc.).
- Use-Oriented (UO): the manufacturer retains the ownership of the product, and the customer is charged a cost for the handling or availability of the product (i.e., sharing, leasing, etc).
- Result-Oriented (RO): the provider or manufacturer is responsible for delivering a result that answers the customer's requirements. In this case, ownership and use are within the manufacturer's control: the provider has the greatest extent of freedom to deliver the result sought by the paying customer: innovation and value maximization are most prevalent in these forms of systems (Tukker, 2004; Ostaeyen, 2014).

The literature is rich with studies that have taken a deeper look at the application PSSs in various manufacturing and industrial ambits, putting forth PSS models, tools, and methods to aid PSS providers in the implementation of those solutions. The analysis of these studies sheds light on the UO systems as being the most popular and adopted approaches and PSS suppliers enhance the maintenance services to ensure optimal use of the product from a customer, environmental and economic point of view. In fact, such systems facilitate building a long-term customer-provider relationship due to the inherent interactions and continuous feedback among others (Metz et al. 2016; Haber and Fargnoli 2017b).

2.2 Building Information Modeling (BIM)

BIM is a process consisting of numerous technologies and tools used in the management and creation of physical places according to selected functional characteristics (Eastman et al. 2008; British Standards Institution 2019). The effectiveness of the BIM depends on the employed information details: since the BIM relies on tools and technologies, the depth and level of assessment of the design features as well as the information related to facility operations and management are key (Denis et al. 2018). The higher level of detail leads to a more effective BIM output. Jiang et al. (2016) noted the transition in the use of BIM from a construction design tool in the direction of a more comprehensive support tool to manage the different stages of a facility's lifespan. Consequently, it can promote collaboration between the stakeholders, notably those heavily involved in the management of a building or a facility's assets, i.e., maintenance activities and operations (Antwi-Afari et al. 2018).
In other words, the use of BIM supports engineers and designers in the decision-making process by enabling them to handle and assess large amounts of information more easily. This easily leads to better knowledge exchange and creation processes enabling the PSS provider to capture all of the main elements and data of the building's global life cycle with continuous monitoring and examination of the building's operational stages (Rock et al. 2018; Eleftheriadis 2017). Several researchers addressed the use of BIM-based solutions in a facility context. For instance, Dong et al. (2014) proposed an infrastructure management relying on BIM for the detection and diagnostic of defects and faults related to heating and ventilation systems; in detail, a dynamic building operational system was conceived and designed via dedicated software. Chen et al. (2018) proposed a maintenance management tool to schedule maintenance activities more effectively. Re Cecconi et al. (2017) focused on improving the management of production equipment status from a BIM point of view. Li et al. (2017) handled the refurbishing of building and facility equipment through BIM-reliant methods.

Other research exists in the literature and the vast majority weakly adopt a life cycle approach, i.e., managing the activities taking a life cycle perspective. Therefore, and as emphasized by Hosseini et al. (2018), a deeper investigation of the application of BIM to the improvement of the management of facility activities and operations is required. They also stressed on the need to adopt a multidisciplinary approach involving different actors and processes. More recently, Adanič et al. (2021) highlighted the potential benefits of BIM-based technologies in supporting mechanical engineering activities such as manufacturing, assembly, and maintenance of mechanical subsystems for Architecture, Engineering, Construction, and Owner-Operator (AECO) projects. In their review study they foster the integration of BIM within operations management of buildings' mechanical components and integrated subsystems their sustainable life cycle management.

2.3 Research Matters

From the above considerations and in the line with the research hints established previously, BIM is presented as a PSS support tool that can aid in the management of facility and building equipment, notably the maintenance activities and operations. In particular, a BIM-PSS integrated approach would allow providers to benefit from the individual attributes of each. First, a PSS inherently assembles its stakeholders towards the adoption of a global comprehensive approach, i.e., a life-cycle oriented one, where the provider maintains product ownership and assumes better responsibility regarding the management of the equipment. Second, BIM handles the information and data flow regarding the facilities as well as the related equipment. Consequently, this communication allows real-time analysis of the behavior of the product and thus facilitate the management of the operations.
These matters are not largely developed to this day despite the high potential residing in the combination of the features of BIM and PSSs for enhancing the management of the facilities and their associated operations. The following sections attempt to narrow the gap by shedding more light on these issues and answering the above RQs.

3. Research approach

Commonly, the facility equipment supplier offers the customers the building equipment and charges them a 'use fee' for a certain period. The fee takes into consideration the costs needed to produce, distribute, and maintain the product for that specific duration: training sessions, customer care activities, maintenance, upgrades, disposal schemes etc. In other words, the supplier receives a request from a customer, which is then translated into technical and contractual terms. The supplier plans and organizes the needed activities and processes to set up their equipment. The equipment is supplied to the customer, i.e., installation and operational qualification. Training is provided to the customer via the supplier's qualified team or authorized third parties. Ordinary maintenance activities are planned and coordinated by the supplier or their subsidiaries. Customer care is placed at the customer's disposal for remote troubleshooting when possible as well as setting up extra-ordinary interventions. End-of-life activities such as disposal, recovery or reconditioning are taken care of by the supplier or their affiliates. In this environment, maintenance services are often taken care of by external firms and companies. Consequently, given the dissociation between the supplier and these additional stakeholders, these situations cannot be properly considered within a PSS scope (Fargnoli et al. 2019). A proper PSS would see the building equipment manufacturer provide "all" of the needed services. This is facilitated by the more simplified and direct information exchange between the provider and the customer whereas the use of external organizations usually hinders this.

To respond to these concerns, BIM is a promising tool: McArthur (2015) notes that BIM enables a "push & pull" process: BIM gives updated information concerning the system whereas the data needed for maintenance operations are 'pulled', i.e., triggered by the customer or user of the equipment. The management of the maintenance activities as well as the importance of having a reliable information flow to oversee is highlighted by several researchers such as Love et al. (2014) and Pishdad-Bozorgi et al. (2018) who hinted the use of BIM as a possible remedy for these issues. This information is not only limited to the technical data of the equipment but is extended to that of the customer and his necessities regarding the maintenance management and operations plans.

According to Vasantha et al. (2012), a PSS approach requires a minimum set of requirements to capture the main customer requirements as well as to define the technical and engineering characteristics that will constitute the backbone of the PSS model. In the context of this research, the Functional-Engineered Product-Service System (FEPSS) brought forward by Haber et al. (2017) will be used as a reference framework. In detail, our proposed approach is depicted in table 1.

Table 1. The proposed approach

INPUT	ACTIVITY	OUTPUT	TOOL
Customer information	Identification of customer needs	Customer Requirements (CRs)	Customer surveys
CRs	CR evaluation	Prioritized CRs	Quality Function Deployment (Akao 1990); Likert scale (Likert 1932)
Provider information (technical experts)	Definition of the technical characteristics	PSS Engineering Characteristics (ECs)	Interviews
Provider information	Assessment of the relationships between the CRs and the ECs	Prioritized ECs	Quality Function Deployment
Provider information and EC	Definition of the PSS parts	PSS parts	Quality Function Deployment
PSS parts	Maintenance management	Maintenance management schedule	BIM model

Such a scheme can be used as a step-by-step guideline to identify customer requirements (CRs) and utilize them to develop a PSS concept, where CRs and ECs of the system (i.e. the PSS features) are defined through the use of the Quality Function Deployment (QFD) method while maintenance services are managed via BIM tools.

3.1 Definition of the PSS features

The Quality Function deployment (QFD) method (Akao 1990) is a well-known tool used to support engineers in meeting customers' requirements and needs for a product or a service (Fargnoli and Sakao 2017). The core of the method is the set of matrices called "House of Quality" (HoQ), which is based on a cause-effect mechanism, which relates the Customer Requirements (CRs) with Engineering Characteristics (ECs) employing a relationship matrix (ReVelle et al., 1998), also enabling an assessment and prioritization of both (Fargnoli et al. 2021). A general scheme of the HoQ is provided in Figure 1.

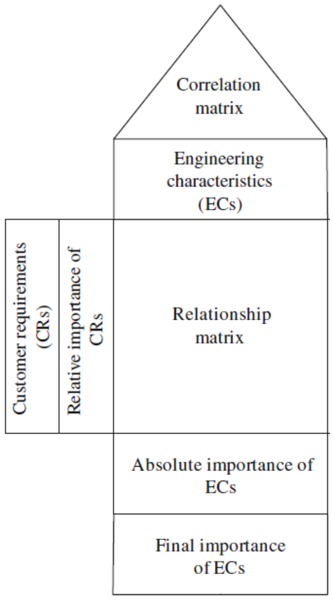

Figure 1. Scheme of the House of Quality (HoQ)

In this study we used the first two phases of QFD to elicit the engineering characteristics of the PSS (phase 1) and the engineering parts (phase 2), which are related to both physical and service features, focusing on the definition of the latter (figure 2).

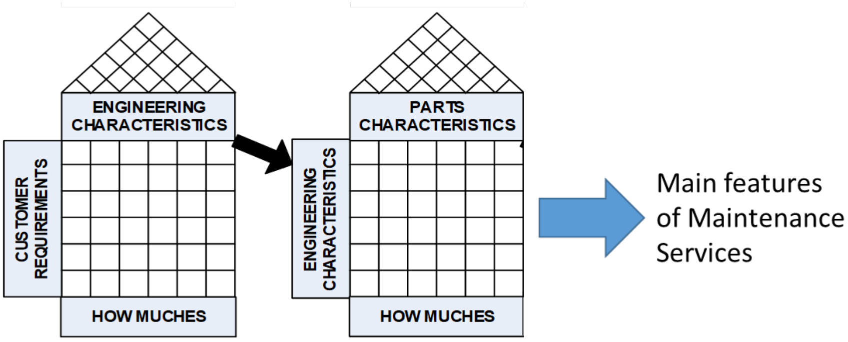

Figure 2. Scheme of the proposed use of QFD

3.2 BIM implementation

BIM-based tools (Figure 3) allow the digital representation of the physical and functional characteristics of a facility creating a shared knowledge resource for information about it, which can be used for decision making during its whole life cycle (WBGD, 2022). BIM applications can be distinguished in the following:

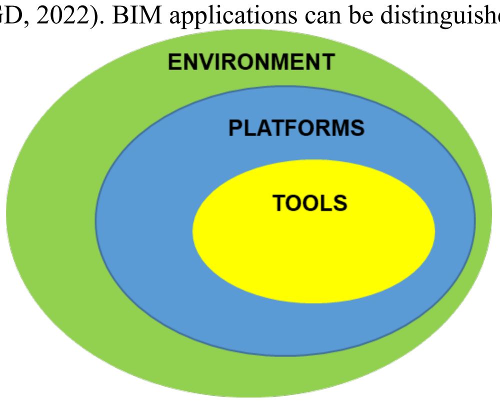

Figure 3. Scheme of the BIM application

A BIM tool is a task-specific application with a specific goal and output (for instance, tools for drawing, costs' evaluation, error checking, energy analysis, rendering, activities' scheduling, etc.), while on the other side a BIM environment includes tools and platforms, allowing the management of data and the company interfaces. However, depending on the specific context, BIM platforms can be considered BIM environments as they allow the management of objects and rules. More in practice, the implementation procedure of a BIM application from which to gather information for facility management can be summarized in the following main steps (Gerrish et al. 2017):

- Definition of the operative context
- Definition of the customers and facility manager needs and expectations
- Definition of the system characteristics (both physical objects and services features)
- Definition of the monitoring activities/scheduling
- Definition of the maintenance management

As illustrated by Farghaly et al. (2018) such an implementation implies the management of a large amount of information that can be ascribed to the following categories and parameters:

- Space/location (e.g., building name, facility type, zone name, zone ID, etc.)
- Classification (e.g., Revit category, Revit ID, type name, asset type, etc.)
- Specifications (e.g., manufacturer, supplier, model name, serial number, etc.)
- Warranty (e.g., installation date, installation guide, certificates, warranty duration, etc.)
- Maintenance (e.g., status, history, scope, frequency, instructions, etc.)

It has to be noted that in the above categories, the information related to costs is not included. Moreover, while in the classification category the Revit is one of the most diffused software for BIM parametric modelling (AutoDesk 2022).

4. Case study

The case study takes place at a five-story governmental building serving as a training facility (Figure 4). The building is equipped of five elevators. This public entity, i.e., the building owner will be referred to as "Company X". Company X currently outsources its maintenance services to a specialized maintenance services firm. Given the nature of this building and the high flow of people using the facility on one hand, and the degraded state of the elevators on the other, company X is seeking to replace them. Hence emerged the need for a feasibility study concerning the deployment of a PSS solution for the provision of five new elevators and their maintenance.

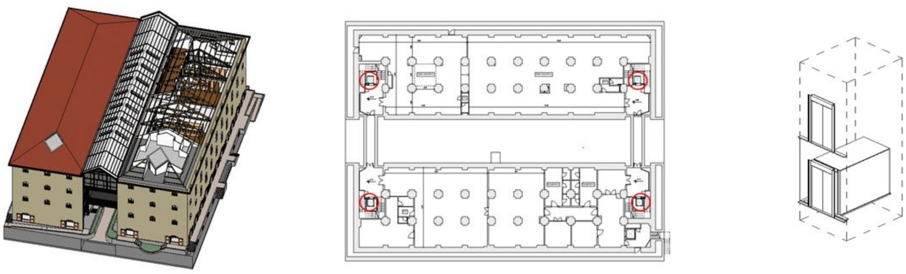

Figure 4. 3D and 2D models of the governmental building and elevator

Primarily, surveys were sent to representatives of company X as well as frequent elevator users to better grasp their expectations and consequently identify their needs. 95 of 124 respondents provided complete results leading to the definition of the CRs, which were assessed on a 1-to-5 Likert scale where 1 signifies a very low importance and 5 indicates a very high one. Secondly, the designers and engineers of company X were interviewed to bring forward two matters: a better understanding of needed elevator types and performance, and the definition of the PSS ECs that can meet the CRs. The relationships between the ECs and the CRs were then assessed using the 1-3-9 criteria where 1 represents a weak relationship, 3 a medium relationship, and 9 a strong one.

For a better visibility, the absence of a relationship is shown via an empty case instead of 0 (Franceschini and Rupil 1999). This results in the application of the QFD's House of Quality (HoQ) which can be seen in Figure 5.

	CR importance	CR relative importance	CR Rank	EC1. Ergonomics of the control panel	EC2. Ergonomics of the buttons	EC3. Dimensions	EC4. Weight load tolerance	EC5. Time for response	EC6. Availability of spare parts	EC7. Quality of customer care service	EC8. Availability of safety indicators (e.g., load warning, proximity to doors, etc.)	EC9. Operational hours of customer care	EC10. Remote monitoring system
CR1. Ease of usability	3,8	13%	5	9	9	3				1			
CR2. Ease of maintenance	4,4	16%	3					9	9	3		3	3
CR3. Capacity	4,2	15%	4			9	9				1		
CR4. Reliability of the elevator	4,6	16%	1					9	3	3	3		3
CR5. Safety	4,5	16%	2				3	3			9		
CR6. Technical support availability	3,6	13%	6	1				9	9	9		9	1
CR7. Data logging	3,1	11%	7				1			1	3		9
EC importance				37,8	34,2	49,2	54,4	126,9	85,8	66,3	67,8	45,6	58,5
EC relative importance				6%	5%	8%	9%	20%	14%	11%	11%	7%	9%
EC rank				9	10	7	6	1	2	4	3	8	5

Figure 5. Application of the HoQ

In a similar manner, meetings were held with the company's team of experts enabled us to define the PSS part characteristics which were evaluated using the HoQ of the second phase of the QFD. From the services' point of view the output of this stage concerned the definition of the following aspects: type of maintenance intervention, start and end time of the maintenance intervention, component installation, emergency system inspection, etc.

The company currently outsources its maintenance activities to a third-party through an annual contract consisting of monthly inspections to ensure the proper functioning of the elevator, rapid intervention in case of a safety-related defect, cleaning and fluid replenishment etc. Extraordinary interventions however are excluded from the contract and carried out on a case-by-case basis. In detail, straightforward and simple repairs are carried out directly. The company uses a cost threshold to broadly filter them. For the more complex interventions, whose costs generally surpass the previous ones, they are submitted to the facility manager for approval. In those situations, a pre-intervention visit is scheduled where the service technician assesses the defects and the necessary actions to remediate them. Analyzing the historical data, we noted an average decision time of seven working days between the request and its acceptance (the elevator being unusable in the meantime), planning and scheduling were not communicated in an organized manner (delays, incomplete information, etc.) and were carried out independently: since each elevator was 'diagnosed' separately, more than one elevator was out of service simultaneously.

A detailed analysis of the maintenance data enabled us to denote the maintenance operations information such as the type of intervention, the date, start and end times, inspection elements, needed components, future inspection dates etc. With the obtained information, and having reviewed the existing maintenance documents, maintenance plans were put into practice through the BIM approach utilizing REVIT© software (Ferrandiz et al. 2018). In detail, REVIT© makes use of abaci (figure 6) to represent the needed information (table 2).

Table 2. Excerpt of the information portrayed in the REVIT abaci.

Ordinary maintenance schedule	Code	Extraordinary maintenance schedule	Code
Date of next maintenance, it is the date when the maintenance activities should be done. They are fixed, and they are known before the event occurs.	**A**	Failure identification	**A**
Effective date of maintenance activity: it is the date when the maintenance operations are done since there may be delay.	**B**	Date of failure identification	**B**
…	…	…	…
Why Customer Care Service is not available, it is necessary when the customer care service is not available and the reason of not availability should be	**R**	Notes	**P**

known. The causes can be different, non-working alarm alert or people away from their place of duty.			

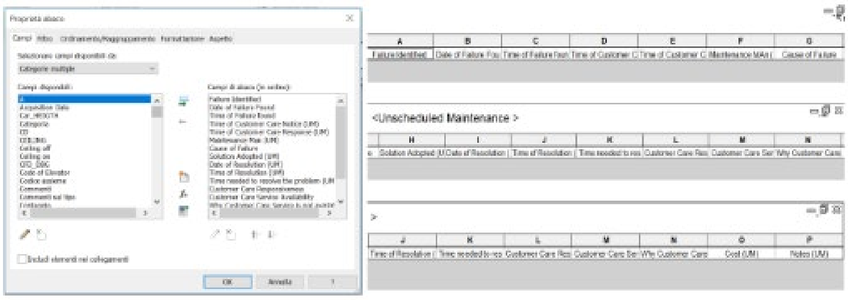

Figure 6. Illustration of the REVIT interface

With the above information, we put in place new maintenance plans filling in the required fields in the abaci. An example can be seen in figure 7 where the start and end dates of a maintenance intervention are defined leading to specifying the planned duration of the maintenance intervention time (figure 7).

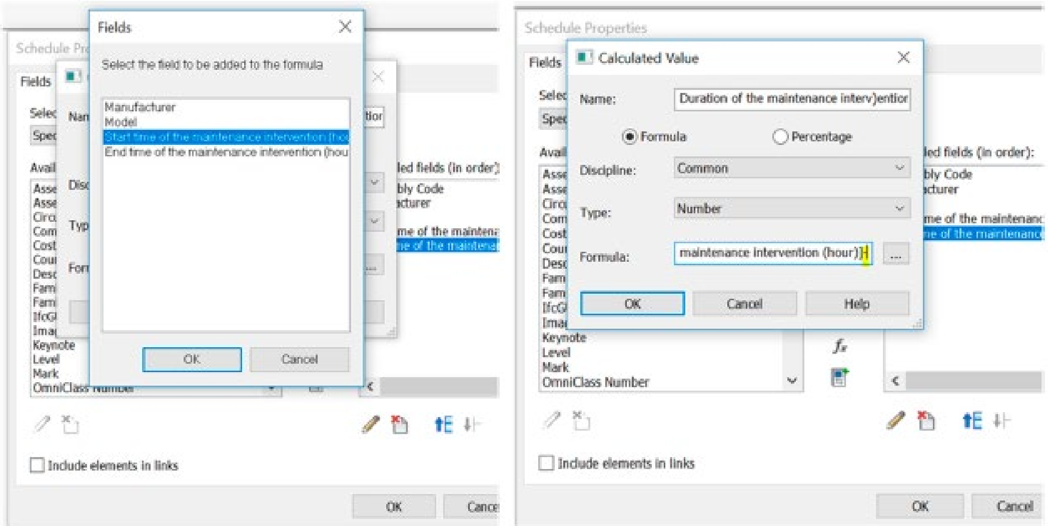

Figure 7. Maintenance planning illustration

5. Discussion of the results

Despite the limited data shown in the case study, mainly due to privacy concerns, the case study brought forth the advantages that can be achieved when integrating BIM during the development of an integrated product-service solution seeking to ameliorate the management of the maintenance operations. The PSS approach enabled us to specify the PSS characteristics and parts that are customer relevant. Afterwards, BIM enabled us to implement them in a holistic database for an effective management of the maintenance service operations, via employing abaci. Practically speaking, the following information came out following the investigation of the data:

- Thirty-four days a year, the elevators are out of service due to an information exchange regarding extraordinary interventions whose costs surpassed the threshold limit.
- Twenty-nine days of limited availability of the elevators can be mitigated given that planned inspections take place on three separate occasions a month instead of two.
- From the data submitted to the facility manager, it emerged that four planned interventions did not take place as required. They were reported to the following month, unfortunately extending the unavailability period of the elevators. Conversely, the proposed model would have avoided this while supplying the facility manager with concise and on-time information.
- BIM can limit the unavailability period of the elevators by adequately and effectively supplying spare parts through efficacious anticipating and planning.

- Over a five-year timespan, the intervention costs are nearly equal to those of the acquisition of a new, similar elevator.
- Improper documentation of the interventions required the facility manager to submit additional requests to obtain them.

Furthermore, it should be noted that these hindrances lead to unsatisfied customers, i.e., elevator users and the manager generating dissatisfaction towards the facility and its management. To counteract, a BIM-PSS model can help resolve these concerns as:

- Ordinary maintenance can take place in due time since all the information will be registered and updated as needed. Accordingly, any missing or unnecessary activity can be addressed leading to costs minimization, reduced downtime and overall higher availability and extended life cycle of the product, i.e., the elevator.
- Extraordinary maintenance can be supplied more rapidly given the real-time information exchange that BIM allows. Hence, whether it is the facility manager necessitating the data or the service provider, shorter response and reactivity times can be clocked, thus augmenting customer satisfaction.
- Easier access to the intervention information: type, the number of components as well as what repair actions are necessary. Spare parts can be managed more effectively, and their supply is faster.
- Centralizing the data in the BIM system: any information can be found more easily and updated more smoothly. This would reflect the current state of the elevator's components enabling more straightforward surveillance of the parameters and consequently easing carrying out the ordinary (and extraordinary) maintenance operations.

Additionally, the safety conditions regarding the functioning of the elevator are also improved and should not be taken lightly. First, integrating the obligatory safety requirements in a BIM model feeds into the main benefit of BIM: easily accessible information with reduced risks of information mismanagement or loss. Traceability is therefore improved as all the records can be securely stored especially when BIM is augmented with smart technologies (Wetzel and Thabet 2015). Second, given that a PSS envisages the provider's ownership retention of the facility equipment, the risk of incorrect management activities taking place is greatly reduced. These elements answer RQ1.

From a broader perspective, the paper presents a practical way of integrating BIM and PSS as means of facilitating the adoption of digital technologies as a value-generating catalyst. The approach brings to light a versatile framework for optimizing the management of maintenance activities and operations as this need was highlighted by Matarneh et al. (2019). Cloud services, remote monitoring, mobile applications etc. are further examples of digital tools that can improve the maintenance and facility management activities, answering RQ2.

Regardless of the advantages exposed in the research, some limitations should not be omitted. For starters, the implementation of the approach is at its preliminary stages and has not been widely implemented (and assessed). Extended data validation on one hand as well as a life cycle assessment should take place to evaluate the feasibility and viability. Also, the knowledge management aspect of BIM and its tools was not explicated. The shift to a PSS partially resolves this since the provider, by retaining ownership of the equipment, possesses the key information related to the equipment. However, its exchange with the customer, i.e., the facility manager, should be better evaluated to better capture the needs of all of the stakeholders.

6. Concluding remarks

In conclusion, this study aimed at augmenting knowledge in the field of servitization proposing a case study research that integrates the PSS approach with Industry 4.0 technologies to improve maintenance management of building facilities such as the elevators. The positive output of this initial study has demonstrated the potential benefits that can be achieved by means of the application of PSS in facility management with the support of recent digital technologies. Further research is expected to validate the proposed approach also extending it to different contexts such as industrial plants and factories.

References

Acerbi F., Sassanelli, C., Terzi, S. and Taisch, M., A systematic literature review on data and information required for circular manufacturing strategies adoption, *Sustainability*, vol. 13, no. 4, pp. 2047, 2021.

Adanič, L., de Oliveira, S. G. and Tibaut, A., BIM and mechanical engineering—a cross-disciplinary analysis, *Sustainability*, vol. 13, no. 8, pp. 4108, 2021.

Antwi-Afari, M. F., Li, H., Pärn, E. A. and Edwards, D. J., Critical success factors for implementing building information modelling (BIM): a longitudinal review. *Automation in Construction*, vol. 91, pp. 100–110, 2018.

Ardolino, M., Rapaccini, M., Saccani, N., Gaiardelli, P., Crespi, G. and Ruggeri, C., The role of digital technologies for the service transformation of industrial companies, *International Journal of Production Research*, vol. 56, pp. 2116–2132, 2018.

Arai, T. and Shimomura, Y., Service CAD System-Evaluation and Quantification, *CIRP Annals-Manufacturing Technology,* vol. 54, no. 1, pp. 463-466, 2005.

AutoDesk, Key features of Revit: https://www.autodesk.com/products/revit/features

Bertoni, A. and Larsson, T., Data mining in product service systems design: literature review and research questions. *Procedia CIRP*, vol. 64, pp. 306–311, 2017.

Beuren, F., Ferreira, M. and Miguel, P., Product service systems: a literature review on integrated products and services, *Journal of Cleaner Production*, vol. 47 no. 5, pp. 222-231, 2013.

Bortoluzzi, G., Chiarvesio, M., Romanello, R., Tabacco, R. and Veglio, V., Industry 4.0 technologies and the servitization strategy: a good match?, *Sinergie Italian Journal of Management*, vol. 38, no.1, pp. 55-72, 2020.

British Standards Institution, *BS EN ISO 19650: Organisation and digitisation of information about buildings and civil engineering works, including building information modelling - Information management using building information modelling*, London: BSI, 2019.

Bynum, P., Issa, R. R. and Olbina, S., Building information modeling in support of sustainable design and construction, *Journal of Construction Engineering and Management*, vol. 139, no. 1, pp. 24-34, 2013.

Chen, Y. and Jupp, J., Model-based systems engineering and through-life information management in complex construction, *Proceedings of the IFIP International Conference on Product Lifecycle Management*, pp. 80–92, Turin, Italy, July 2-4, 2018.

Denis, F., Vandervaeren, C. and De Temmerman, N., Using Network Analysis and BIM to Quantify the Impact of Design for Disassembly, *Buildings*, vol. 8, pp. 113, 2018.

Dalenogare, L. S., Baseggio, M. M., Ayala, N. F., Le Dain, M. A. and Frank, A. G., The contribution of Smart Glasses for PSS, *Procedia CIRP*, vol. 83, pp. 318-323, 2019.

Dong, B., O'Neill, Z. and Li, Z., A BIM-enabled information infrastructure for building energy fault detection and diagnostics, *Automation in Construction*, vol. 44, pp. 197–211, 2014.

Eastman, C., Tiecholz, P., Sacks, R. and Liston, K., *BIM Handbook: a guide to building information modeling for owners, managers, designers, engineers, and contractors*, 1st Edition, Hoboken, New Jersey: John Wiley, 2008.

Eleftheriadis, S., Mumovic, D. and Greening, P., Life cycle energy e_ciency in building structures: A review of current developments and future outlooks based on BIM capabilities, *Renewable and Sustainable Energy Reviews*, vol. 67, pp. 811–825, 2017.

Farghaly, K., Abanda, F. H., Vidalakis, C., and Wood, G. Taxonomy for BIM and asset management semantic interoperability. *Journal of Management in Engineering*, vol. 34, no. 4, pp. 04018012, 2018.

Fargnoli, M., Lleshaj, A., Lombardi, M., Sciarretta, N. and Di Gravio, G., A BIM-based PSS approach for the management of maintenance operations of building equipment, *Buildings*, vol. 9, no. 6, pp. 139, 2019a.

Fargnoli, M., Haber, N. and Sakao, T., PSS modularisation: a customer-driven integrated approach, *International Journal of Production Research*, vol. 57, no. 13, pp. 4061-4077, 2019b.

Fargnoli, M., Haber, N., Platti, D., Tronci, M. The soft side of QFD: a comparative study on customer requirements' prioritization in the food sector. *Proceedings of the 4th European International Conference on Industrial Engineering and Operations Management*, pp. 78-89, Rome, Italy, August 2-5, 2021.

Franceschini, F. and Rupil, A., Rating scales and prioritization in QFD, *International Journal of Quality and Reliability Management*, 1999.

Gerrish, T., Ruikar, K., Cook, M., Johnson, M., Phillip, M., and Lowry, C. BIM application to building energy performance visualisation and management: Challenges and potential. *Energy and Buildings*, vol. 144, pp. 218-228.

Haber, N. and Fargnoli, M., Designing product-service systems: a review towards a unified approach, *Proceedings of International Conference on Industrial Engineering and Operations Management*, pp. 817-837, Rabat, Morocco, April 11-13, 2017a

Haber, N. and Fargnoli, M., Design for product-service systems: a procedure to enhance functional integration of product-service offerings. *International Journal of Product Development*, vol. 22, pp. 135–164, 2017b.

Haber, N., Fargnoli, M., Tronci, M. and Ababneh, A., Designing ecofriendly Product-Service Systems (PSSs) through morphological reasoning, *Proceedings of the International Conference on Industrial Engineering and Operations Management*, pp. 26-27, Paris, France, July 26-27, 2018.

Hernández, J., Martín Lerones, P., Bonsma, P., van Delft, A., Deighton, R. and Braun, J. D., An IFC interoperability framework for self-inspection process in buildings, *Buildings*, vol. 8, pp. 32, 2018.

Hosseini, M. R., Roelvink, R., Papadonikolaki, E., Edwards, D. J. and Pärn, E. Integrating BIM into facility management: typology matrix of information handover requirements, *International Journal of Building Pathology and Adaptation*, vol. 36, pp. 2–14, 2018.

Kensek, K., *Building information modeling*. Routledge, 2014.

Li, J., Ng, S. T. and Skitmore, M., Review of low-carbon refurbishment solutions for residential buildings with particular reference to multi-story buildings in Hong Kong, *Renewable and Sustainable Energy Reviews*, vol. 73, pp. 393–407, 2017.

Love, P. E., Matthews, J., Simpson, I., Hill, A. and Olatunji, O. A., A benefits realization management building information modeling framework for asset owners, *Automation in Construction*, vol. 37, pp. 1–10, 2014.

Likert, R., A Technique for the Measurement of Attitudes, *Archives of Psychology*, vol. 140, pp. 1–55, 1932.

Matarneh, S. T., Danso-Amoako, M., Al-Bizri, S., Gaterell, M. and Matarneh, R., Building information modeling for facilities management: a literature review and future research directions, *Journal of Building Engineering*, vol. 24, pp. 100755, 2019.

McArthur, J. J., A building information management (BIM) framework and supporting case study for existing building operations, maintenance and sustainability, *Procedia Engineering*, vol. 118, pp. 1104–1111, 2015.

Metz, P., Burek, S., Hultgren, T. R., Kogan, S. and Schwartz, L., The path to sustainability-driven innovation: environmental sustainability can be the foundation for increasing competitive advantage and the basis for effective innovation, *Research-Technology Management*, vol. 59, pp. 50–61, 2016.

Mont, O., Clarifying the concept of product service system, *Journal of Cleaner Production*, vol. 10, pp. 237-245, 2002.

Pishdad-Bozorgi, P., Gao, X., Eastman, C. and Self, A. P., Planning and developing facility management-enabled building information model (FM-enabled BIM), *Automation in Construction*, vol. 87, pp. 22–38, 2018.

Re Cecconi, F., Maltese, S. and Dejaco, M. C., Leveraging BIM for digital built environment asset management. *Innovation in Infrastructure Solutions,* vol. 2, pp. 14, 2017.

Röck, M., Hollberg, A., Habert, G. and Passer, A., LCA and BIM: visualization of environmental potentials in building construction at early design stages, *Building and Environment*, vol. 140, pp. 153–161, 2018.

Takata, S., Kirnura, F., van Houten, F. J., Westkamper, E., Shpitalni, M., Ceglarek, D. and Lee, J., Maintenance: changing role in life cycle management, *CIRP Annals*, vol. 53, no. 2, pp. 643-655, 2004.

Tran, T. and Park, J., Development of a novel set of criteria to select methodology for designing product service systems, *Journal of Computational Design and Engineering*, vol. 3 no. 2, pp. 112-120, 2015.

Tukker, A., Eight types of product service system: eight ways to sustainability? Experiences from suspronet, *Business Strategy and The Environment*, vol. 13 no. 4, pp. 246–260, 2004.

Tukker, A., Product services for a resource-efficient and circular economy—a review, *Journal of Cleaner Production*, vol. 97, pp. 76-91, 2015.

Ulaga, W. and Reinartz, W. J., Hybrid offerings: how manufacturing firms combine goods and services successfully, *Journal of Marketing*, vol. 75, pp. 5–23, 2011.

Vezzoli, C., Ceschin, F., Diehl, J. C. and Kohtala, C., New design challenges to widely implement 'Sustainable Product–Service Systems', *Journal of Cleaner Production*, vol. 97, pp. 1-12, 2015.

Wang, N., Ren, S., Liu, Y., Yang, M., Wang, J. and Huisingh, D., An active preventive maintenance approach of complex equipment based on a novel product-service system operation mode, *Journal of Cleaner Production*, vol. 277, pp. 123365, 2020.

Wetzel, E. M. and Thabet, W.Y, The use of a BIM-based framework to support safe facility management processes, *Automation in Construction,* vol. 60, pp. 12–24, 2015.

WBDG - Whole Building Design Guide®, https://www.wbdg.org/bim/, accessed on January 24, 2022.

Wong, J. K. W., Ge, J. and He, S. X., Digitisation in facilities management: a literature review and future research directions, *Automation in Construction*, vol. 92, pp. 312–326, 2018.

Yoji Akao. (2004). Quality function deployment: integrating customer requirements into product design. Steiner Books.

Biographies

Mario Fargnoli is Associate Professor at Universitas Mercatorum of Rome, where he teaches in Industrial Engineering courses. He also works at the Italian Ministry of Agriculture. Until 2021 he was Contract Professor in Safety Engineering courses at Sapienza University of Rome, where he earned his PhD in 2005. Previously he worked at the Department of Precision Machinery of the University of Tokyo as JSPS Fellow Researcher. His research interests mainly concern machinery safety, occupational health and safety (OHS), product service systems (PSS), ecodesign, quality function deployment (QFD), human factors and ergonomics (HFE).

Nicolas Haber is an Industrial Engineer holding a PhD in Industrial Engineering and Engineering Management from Sapienza - University of Rome, which he earned in 2017. His field of research is the design of product-service systems in a sustainable manner. He is currently the technical leader for the development of electronic components for PSA group. He previously worked at Heineken and obtained the 6-Sigma black belt certificate.

Mara Lombardi is Associate Professor at the Department Chemical Engineering Materials Environment (DICMA) of Sapienza - University of Rome, where she earned her PhD in 2008. She is the Coordinator of the master course in Safety Engineering at Sapienza University of Rome and the President of the Mediterranean Network of Engineering Schools (RMEI). Her research activities mainly concern: construction safety, fire safety engineering, occupational health and safety, risk analysis, facility life-cycle management, and Building Information Modelling.

Massimo Tronci, PhD in Energetics, is Full Professor of Industrial Systems Engineering and Director of the PhD School in Industrial and Management Engineering at Sapienza - University of Rome. His teaching activities concern Industrial Systems Engineering, Operations Management and Smart Factory in the Faculty of Civil and Industrial Engineering. His main research topics are: Supply Chain Management, Operations Management, Quality and Safety Management.