BIM+IoT for office spaces optimisation

Sebastiano Maltese
University of Applied Sciences and Arts of Southern Switzerland (SUPSI)
Institute for Applied Sustainability to the Built Environment (ISAAC)
Mendrisio, Switzerland
0000-0002-1635-217X

Domenico Altieri
University of Applied Sciences and Arts of Southern Switzerland (SUPSI)
Institute for Applied Sustainability to the Built Environment (ISAAC)
Mendrisio, Switzerland
domenico.altieri@supsi.ch

Giovanni Branca
University of Applied Sciences and Arts of Southern Switzerland (SUPSI)
Institute for Applied Sustainability to the Built Environment (ISAAC)
Mendrisio, Switzerland
giovanni.branca@supsi.ch

Dario Marvin
University of Applied Sciences and Arts of Southern Switzerland (SUPSI)
Institute for Applied Sustainability to the Built Environment (ISAAC)
Mendrisio, Switzerland
dario.marvin@supsi.ch

***Abstract*— The current pandemic period has to some extent changed the conception and use of classic workplaces and as a result owners and tenants aim to recalibrate operating costs by improving the building layout, efficiency and performances. The objective of this research is to develop a methodology to address office spaces optimization, in terms of occupancy and efficiency, ensuring at the same time an acceptable level of internal comfort. This process is supported by a live data stream coming from IoT sensors and linked to BIM objects (spaces, components) to create a simplified digital twin providing georeferenced data. Data about space usage, thermal comfort and equipment performances can be used effectively to lower running costs and boost productivity through dedicated optimization algorithms. BIM is not usually associated with existing buildings and even less with retrofit or data analysis, due to the expected modelling time. The idea is to overcome this paradigm, by demonstrating that with existing technologies is possible to achieve a fast and incremental BIM model, which combined with real-time data, can be useful for upgrading the operational efficiency of an asset. Currently, authors are setting up a case study with a small network of sensors to gather and analyze data about occupancy and environmental parameters of an open space in the new SUPSI DACD Campus of Mendrisio (Switzerland, Ticino). This approach can be further developed by gathering and analyzing additional parameters in order to investigate the possibility of improving other aspects of the operational phase of office buildings. This research applies to medium-large portfolios and is not targeted to private owners.**

Keywords—BIM, IoT, office, portfolio, optimization, comfort

I. INTRODUCTION

This paragraph provides context and motivation of the research, together with the objectives and the organization of the paper.

A. Context

The real estate sector faces new challenges, additional to the improved attention to energy efficiency: owners, both public and private, are well aware of the need of reducing operational impacts and energy retrofit solutions are continuously implemented, also thanks to national programs and incentives. However, impacts reduction in the operational phase do not come only from retrofit interventions, but also from an increased efficiency provided by additional aspects to be considered, namely occupancy, users' efficiency/productivity and change of use, while keeping an adequate level of comfort. In this context, a post-occupancy evaluation represents an effective approach to analyze different aspects characterizing the building operational stage, potentially leading to an iterative performances improvement of existing facilities with even the ability of benchmark multiple properties, especially if part of the same stock (e.g. [1],[2]). These aspects can be better analyzed in office and tertiary buildings, which are also currently suffering vacancy issues. New technologies, such as digital twins enabled by IoT sensors, are investigated in this research aiming at improving overall operational efficiency of existing office buildings. Digital twins are currently seen in combination with new constructions and/or new buildings with built-in home automation/BMS; the idea of this project is to leverage the use of BIM also for existing buildings, by providing reliable processes and workflows for the real estate operation and maintenance.

B. Objectives

The OptiSpace project aims at optimizing the use of existing office buildings, striking a balance between users' comfort, energy savings and occupation. Moreover, monitoring of crowds could be investigated, due to current needs brought by the pandemic. The final scope of the project is to address office spaces optimization with an analytic approach, trying to figure out a possible process to be implemented firstly in case studies and then in real portfolios. This paper can be considered a research statement, as it shows requirements and needs of this project.

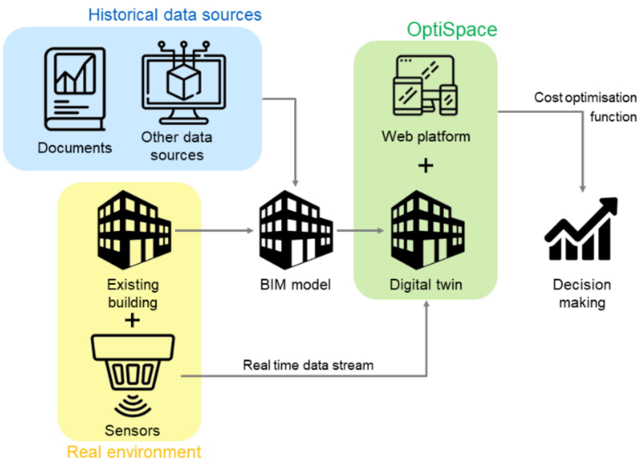

Fig. 1. General scheme of the project

The scheme in **Errore. L'origine riferimento non è stata trovata.** shows the general objective of the project, which is to develop (or adapt) a platform for the management of a digital twin, enabled by IoT data. The BIM model is considered the union of geometrical and alphanumerical data, but it becomes a living entity (a digital twin) with the addition of real-time data and a proper management structure.

II. SURVEY OF STAKEHOLDERS' NEEDS

The state of the art section of the paper has been given a practical focus, as this study is the preliminary step of a potential Innosuisse project. This research has been targeted mainly in understanding requirements and needs, as well as their interest in the topic, of potential clients: large portfolio owners and public managers (municipalities, Cantons, hospitals, etc.). Here the main objectives addressed in collaboration an industrial partner.

- Collection of owners' and users' needs and requirements about existing office spaces usage;
- Identification of the most cost-effective state of the art IoT sensors in connection to spaces;
- Identification of the criteria for the optimal IoT sensors selection and positioning;
- Identification and development of design variables connected to the Key Performance Indicators to be controlled.

The first achievement of the project is the collection of stakeholders' needs and desires. A survey has been conducted to gather data about the project, especially regarding clients' needs and requirements about spaces optimization. The survey targeted public managers of buildings and portfolios, namely municipalities, hospitals and pension funds all over Switzerland. The questionnaire has been filled at the end of 2020. Although the answer rate has not been as high as expected, we collected 59 answers (out of about 1'000 questionnaires sent); among them: 20 complete answers, 11 incomplete but interesting answers and 28 incomplete answers. Main results are synthesized here:

- **Respondent data.** The majority of respondents are municipal employees, with building manager role;
- **Building stock.** Most of the spaces managed are single or multi-desk offices and meeting rooms. There were fewer open spaces than expected (although with these limited results this trend could change). This leads to the question of efficiency of space usage, in terms of occupation and comfort;
- **Activities.** The answers show that managers need to perform a wide number of activities, with a focus on cleaning and illumination. This leads to a wide range of activities that could possibly be optimized by the project, but we firstly need to focus on our main objectives: comfort, costs and occupation;
- **Real-time detection and comfort.** Many small municipalities are not interested in real-time monitoring and the comfort is a relatively important topic, in terms of data analysis. On the other hand, from the respondents answer we understand that comfort is considered important, but not adequately monitored (usually through punctual tests, qualitative analysis or none of the previous). This potentially leads to an interface where Key Performance Indicators may be periodically checked, without the need of a complex real-time interface. This aspect is particularly meaningful, as an important decision to be made in the project is relative to controlling vs monitoring, that is, allowing the interaction with systems (e.g. heating, cooling, ventilation);
- **Digitisation.** The digitisation of buildings is generally low: the majority of respondents still refers to paper plans and CAD 2D drawings. BIM models are present in less than the 25% of the respondents' portfolios. This opens various digitisation alternatives, to be investigated by the OptiSpace project.

The main idea of the survey and the project in general revolves around understanding which input must be gathered in order to answer the question of optimizing space occupancy by respecting comfort and cost target levels. The importance and potential of each single input is to be analyzed as well in order to deepen our understanding of the problem. Furthermore, another element to be analyzed in the project is the connection with the BIM process, which provides important tools for visualisation and interaction, but requires an investment in technology and process reorganization in order to be fully effective. This reorganization can be seen as an opportunity to deliver new services to clients: e.g. digitisation of the built environment, standardization of procedures and BIM models, connection to CAFM (Computer-Aided Facility Management) software, everything in connection with the IoT-based KPIs under analysis. The main results are summarized below, in connection with these three aspects: a) Parameters optimization and implications; b) Possibilities offered by IoT technologies; and c) Possibilities offered by digitisation and BIM.

A quantitative and typological optimization analysis of the space occupancy levels requires a preliminary phase to identify the variables of interest that characterize key indicators linked to operating costs and occupant well-being. One of the project goals is the definition of a framework of real-time data analysis in order to guarantee an optimal occupancy respecting productivity and cost targets required by the client.

III. APPROACH

A **feasibility study was conducted to identify and define a cost optimization process based on real-time data from on-site sensors**. A cost function is therefore needed and will be defined starting from the degree of space occupancy, which in turn is assumed to be an indirect indicator of the expected services and consumptions of a building, such as: cleaning services, administrative services, security services and variations in electricity consumption.

A. Optimisation

The "**cost-occupancy**" relationship is a function of both the type and the intended use of the analyzed building and its accurate definition requires additional initial monitoring and calibration time (Fig. 2). The constraints are not part of the "cost-occupancy" function, as they act as external parameters to be satisfied. The optimization process thus defined aims to identify the optimal degree of occupancy of the analyzed spaces in order to minimize costs in a set of main scenarios, such as corporate co-working and smart working shifts.

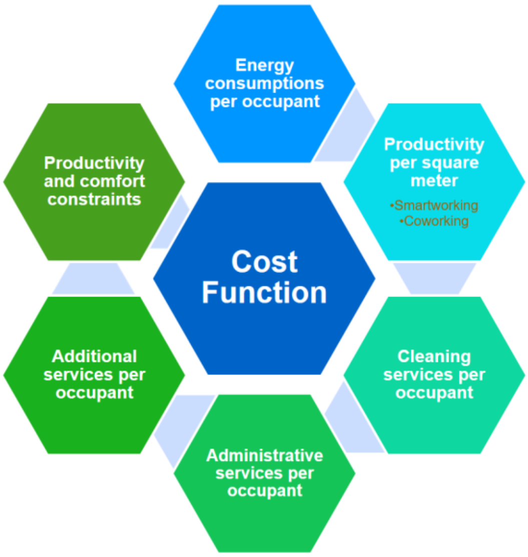

Fig. 2. Cost-function contributions

The pandemic period has in fact revolutionized the world of work, making these types of organization of activities extremely competitive and therefore economically attractive. This preliminary study highlighted the additional need to provide an **accurate estimate of the level of productivity per square meter** of the spaces analyzed in order to be able to possibly introduce in the optimization stage a partial change of the building intended use, with "commercial" being one such option. The comfort data are finally confirmed to be important in order to consider only maximum admissible occupancy levels, without affecting the well-being of the occupants and therefore their final productivity.

B. *Energy management*

The connection of space usage and energy performances is another relevant aspect that has been partially investigated thanks to SUPSI expertise in system optimization (partnership with Energo [3] and PositifGap project [4]). The analysis of the building's energy consumption is not directly part of the proposed optimization process, but rather represents an indirect variable that contributes to the definition of the cost function. An effective Building Energy Management system should in fact be calibrated on data from a set of optimization measures connected to their effects that can be extrapolated from historical data. In the absence of these, real-time data can only be used if driven by a complex adaptive algorithm capable of taking into account a large number of boundary conditions. Nevertheless, the interaction between properly gathered real-time data and an optimization algorithm aiming at optimizing the balance occupation-consumption-comfort, is not easy and requires important investments in terms of systems controls (e.g. BMS and automation). We still deem the analysis of consumptions in combination with comfort and occupancy to be very important, but we do not see an easy way of controlling systems behavior without modifying the systems. In addition to this, office buildings have complex and heterogeneous systems, thus the need of tailored solutions would be required.

C. *Internet of Things (IoT)*

The data acquisition process is a key element for the success of the project. In the past, questionnaires and face-to-face interviews represented the main way to extract information from the building occupants; Post-Occupancy Evaluation (POE) is now supported by an effective set of processes and techniques. Nowadays, real-time data become more and more accessible thanks to the spread of low-cost sensors that can be easily placed in the inner space creating a wireless integrated network with dedicated cloud services. This availability, together with the need to enhance the efficiency of space usage (limited resources, higher standards), leads to the need of new ways of gathering data and analyzing them with cross-domain KPIs. The problem of assessing occupancy of a given room or building can be tackled with the use of individual access cards or RFID tags, which allow a precise count, but are also subject to user compliance. On the other hand, passive measurement of environmental parameters requires no action from the user and it has been shown that the collected signals can be analyzed with the help of specific algorithms to infer occupancy with good precision. Some studies focused on temperature and humidity signals collected in an office room and analyzed the data with smoothing and de-trending techniques to detect significant variations in the measurements. Other studies [5][6] included a more widespread collection of data, gathered from multiple sensors, such as temperature, pressure, humidity, sound pressure, light intensity, motion detection, CO_2 and TVOC. In particular, Adeogun et al., 2019 [6] uses a Forward Neural Network (FNN) to evaluate two possible problems in room occupancy: a binary problem, addressing the question whether at least one person is in the room or not, and a multi-class problem, whose classes are zero people, exactly one person or more than one person in the room. Furthermore, this algorithm allows real time estimation of occupancy. A similar approach could be used in our studies.

D. *Building Information Modelling (BIM)*

BIM is a central topic in this project. Current processes and instruments already allow for a two steps digitisation process: a) point-cloud generation with laser-scanner and/or photogrammetry; and b) manual creation of a BIM model at different level of graphical and information detail (LOG and LOI). While the cost for the first step is more or less fixed, there could be margin for improvement in the generation of the BIM model, reducing costs by automating the process. We also thought about different level of digitisation according to the client's starting point, as instance: a) BIM model generation from point-cloud if no documents are available; b) data extraction and/or BIM automatic generation from 2D drawings; and c) spatial model generation starting from point clouds or drawings. There are multiple services already existing and we do not see ourselves, at least in this preliminary project, in improving existing technologies/ in this area, or even developing a new service devoted only to digitisation. A probable option would be not to develop a new platform from scratch, but to adapt an existing solution to our needs (e.g. BIMserver [7] or other open source platforms like BIM [8] or BIMserver.center 0).

E. *IoT tests*

During these months, we devoted some hours in studying IoT sensors and networks available on the market. From the sensoristic point of view, we implemented the prototype of a data measurement station, which streams a **LoRa** transmitted signal composed of diversified measurements obtained by multiple **IoT sensors**. These nodes can potentially transmit data over a distance of hundreds of meters via a specific radio frequency, thus theoretically not needing constant Wi-Fi connection in all but one node. The stations may gather different data in different locations, based on the purpose of each station and the installed sensors. These sensors may measure **temperature, humidity, pressure, light, sound, movement, CO_2 and TVOC** and they will help us to achieve the final goal of the project, by feeding the necessary data to the algorithm we are going to develop. These experiments, which include data collection, visualisation and analysis can be considered a **preliminary case study** and allowed us to explain to colleagues and clients our future goal. This lead to the experimentation of two case studies, more complex, that will start during 2021. The main objective of these case studies is to gather real data in different environments, to better develop and test the optimization algorithm.

F. Preliminary results

Resuming, this project aims at developing a service based on these innovation points: a) to easily digitise existing office buildings using BIM technologies in combination with laser-scanner/photogrammetry or automated CAD drawing data extraction: e.g. creating a spatial model using IFC protocol (*IfcSpace*) with significant data attached; b) to connect IoT data with BIM models, thus to create a powerful visualisation tool, object-oriented and easy to use; and c) to calculate cross-domain KPIs able to balance comfort, occupancy and operational costs, thus to consider the needs of different categories of stakeholders: users, owners and managers. Today, owners or managers of commercial spaces, and in particular of offices space, find themselves in difficulty to fully occupying their spaces. A good portion of the commercial building are empty or under-occupied. Operating costs remain however high. Owners or managers need solutions to optimize costs and space in order not to lose buildings value, and at the same time new clients are being sought to occupy the proposed rental space. Unfortunately, most owners do not have solutions and are simply waiting for a positive change in the market. The present situation does not allow anymore for more passive waiting: the rental office market needs new solutions as soon as possible.

IV. CONCLUSIONS

This research raised some challenges that need to be carefully analyzed during the development of the project. These aspects will be addressed during the next steps of the research, whilst are shorty described in this paragraph. The first challenge is the creation of the BIM model of an existing building: the starting point is most of the time a 2D CAD drawing, seldom updated, supported by additional 2D paper drawings. Even if the cost of BIM model generation from point clouds is constantly decreasing, this does not necessarily represent the best option, as such level of detail is not always required, as it depends on the optimization objectives. The second challenge is the connection between the BIM model and the IoT sensors, namely creating an unequivocal link between objects and data. There are both open and proprietary solutions to this problem, and it will be required to develop something new or to adapt existing solutions to better fit the needs of the project. Due to the practical nature of this project, it is required to study the applicability on real environment: for case studies and pilots self-assembled IoT sensors are good, but it is necessary to strike a cost/benefit balance, analyzing both open and proprietary solutions to find the best one according to project's objectives. The open-source approach adopted during the first trials is perfect for conducting experiments and gathering data to feed and improve the optimization algorithm. As this research is conducted in combination with an industrial partner, once demonstrated the feasibility, multiple options will be evaluated, including also additional partnerships. In this document, the issue of energy has not been considered, if only marginally, not because of lack of importance, but because of its complexity. Even more difficult is a potential interaction, in which, data coming from IoT sensors trigger a specific action in a system; this could be done if multiple conditions are satisfied and if the system is physically able to do it. Last but not least, the privacy issue: even if current data analytics methodologies are meant to preserve users' privacy, the project will face the need of informing the users and guarantee a correct and transparent treatment of sensible data. The OptiSpace project propose methods and tools to support innovative solutions in this sector. It is in fact possible to optimize operating costs by monitoring the current situation through data collection with sensors, applying innovative analysis methods and appropriate optimization functions. Simultaneously, it is possible to increase revenues by finding new occupancy solutions, thanks to new solutions offered by BIM processes. Trough OptiSpace methodology it is possible to reduce costs and increase revenues in a life cycle discounted cash flow analysis calculation, in order to save or increase the value of the buildings. In the long term, through this methodology it may also be possible to propose scenarios of usage conversion, in a quick and standardized way. Each optimization scenario will be associated with possible costs and benefits by providing a risk analysis.

V. ACKNOWLEDGEMENTS

This project has been funded by Innosuisse with a preliminary study voucher (application no. 48284.1 INNO-EE). The preliminary project has been carried out from 13.09.2021 to 04.03.2021, while the project is still under development in collaboration with Ferraro GmbH.

VI. REFERENCES

[1] Göçer, Özgür, Ying Hua, and Kenan Göçer. "Completing the missing link in building design process: Enhancing post-occupancy evaluation method for effective feedback for building performance." Building and Environment 89 (2015): 14-27.

[2] Olivia, Guerra-Santin, and Tweed Aidan Christopher. "In-use monitoring of buildings: An overview and classification of evaluation methods."Energy and Buildings 86 (2015): 176-189.

[3] Energo, http://www.energo.ch/index.html?p=110 [visited 12.05.2021].

[4] Branca G., Altieri A., Gambato C., Lazarus J. (2019-20121). POSITIFGAP: Définition du postif gap sur la consommation des bâtiments suite aux travaux d'optimisation et rénovations peut invasif (ongoing project developed by SUPSI with the Energo Association and funded by the Federal Energy Office).

[5] S. Zemouri, D. Magoni, A. Zemouri, Y. Gkoufas, K. Katrinis and J. Murphy, "An Edge Computing Approach to Explore Indoor Environmental Sensor Data for Occupancy Measurement in Office Spaces,"2018 IEEE International Smart Cities Conference (ISC2), Kansas City, MO, USA, 2018, pp. 1-8, doi: 10.1109/ISC2.2018.8656753.

[6] R. Adeogun, I. Rodriguez, M. Razzaghpour, G. Berardinelli, P. H. Christensen and P. E. Mogensen, "Indoor Occupancy Detection and Estimation using Machine Learning and Measurements from an IoT LoRa-based Monitoring System," 2019 Global IoT Summit (GIoTS), Aarhus, Denmark, 2019, pp. 1-5, doi: 10.1109/GIOTS.2019.8766374.

[7] BIMserver, github.com/opensourceBIM/BIMserver [visited 12.05.21].

[8] BIMdata, bimdata.io [visited 12.05.21].

BIMserver.center, bimserver.center/en [visited 12.05.21].