The Interface Layer of a BIM-IoT Prototype for Energy Consumption Monitoring

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Abstract

This paper aims at describing the interface layer of a BIM-IoT prototype. The prototype addresses the gap of BIM Model Use (BMU) for energy monitoring by the integration of BIM Models with building systems' energy consumption information in real-time. Such integration requires a BIM/Internet of Things (IoT) Interfacing due to the connection between real and virtual environments as well as context awareness demands. Also, the need for a user-centered feedback strategy concerns about the information delivery and display to enhance predictive maintenance activities and facilities managers' decision-making over Energy Management. The BIM-IoT prototype followed the Design, Development and Evaluation (DDE) steps of the Design Science Research. A pilot implementation at an institutional building restricted to a research laboratory enabled a proof of concept and an analytical assessment of the prototype's capacities. The existing BIM Record Model demanded changes comprising geometric and non-geometric modeling issues (e.g., assets registers) to receive sensor-based dynamic and actual information, and assure its 2D/3D views and semantic context. We observe that the BIM-IoT prototype is a feasible system to support operational strategies based on facilities managers-centered feedback. It contributes to the predictive maintenance and facilitates the comprehension of building systems status and performance. The prototype acts as an accessible and interactive option for energy consumption monitoring.

Keywords

BIM/IoT interfacing • Energy management • Operation and Maintenance

82.1 Introduction

Energy use is expected to have a sharp increase until the middle of 2050 in the Brazilian commercial and public building sectors. The adoption of energy efficiency measures that concerns about building use patterns issues may mitigate that increase [1]. This scenario represents an incentive for owners that build for their own use to regard facilities' Operation and Maintenance (O&M) long-term costs [2].

Efforts concerning building use patterns are consistent to achieve improvements in saving energy [3]. Initiatives in that sense comprise building automation, devices upgrade and behavior changing [4]. Energy Management (EM) becomes relevant as well since energy is not a fixed cost [5]. Recognized in the literature as one of the recurrent types of Facility Management (FM) [6], EM requires the process of analyzing the efficiency of building energy consumption and identifying

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if its cost is competitive. Such circumstances lead to ISO 50001 and building energy performance monitoring, which should produce measurable results involving energy efficiency, use, and consumption [7]. Monitoring the built environment improves problem-solving by allowing real-time data collection, visualization, and analysis [8]. Conventional Building Management Systems (BMS) that own EM modules are capable of measuring actual energy consumption periodically. Though they are regularly programmed and depend on outsourced service to update geometric and non-geometric information of a building (e.g., new floor or asset) [9]. BMS display of collected data is usually in tables, charts or texts, on 2D floor plans and isolated from a 3D environment [10–12]. Furthermore, the majority of those systems lacks interconnectivity between their graphical representations, which brings to the segregation of objects from the building context without the appropriate level of detail [9].

Through the rising adoption of Building Information Modeling (BIM) in Architecture, Engineering, Construction and Operation (AECO) industry and its potential link to BMS, owners can benefit from context awareness provided by BIM models [13]. BIM models are 3D and visually accurate digital building representations that embrace semantic and enriched data [14], allowing a wide range of uses in construction domain [15]. A BIM Model Use (BMU) for energy monitoring is less developed than in other applications. Still, there is an acknowledged potential of integrating BIM models with sensor-based information, which may support real-time energy monitoring and building automation [9]. So potential must consider that in the built environment there is a significant amount of data associated with the functioning and behavior of its objects [10, 11, 16]. Such a scenario of monitoring and control should fit into the Internet of Things (IoT) paradigm, which comprises a set of technologies for embedding intelligence in real-world environments. IoT can be defined as a global network infrastructure to interconnect physical and virtual objects aiming at exploiting collected data and its communication capabilities [17].

This paper aims at describing the interface layer of a BIM-IoT prototype. The prototype addresses the gap of BMU for energy monitoring by the integration of a BIM Model with a building system's actual energy consumption information in real-time. Furthermore, there is a focus on a feedback strategy planned for enhancing predictive maintenance practice and facilities managers' decision-making over Energy Management.

82.2 Related Work

According to [2], BIM Models provide a natural interface with sensors and remote FM operations, which highlight their capacity to support Monitoring and Control practices. Such statement reinforces the integration of BIM and Internet of Things that should consist of using a BIM Model as an interface benefited from data provided through a network of equipment, sensors and mobile devices [15, 18]. The outcomes of BIM/IoT Interfacing for Energy Management may improve the consumption monitoring and control through building automation as well as promote the association of BIM objects with actual data for analysis and prediction. Other outputs may comprise the user's feedback employment to reduce consumption, the historical usage reports enhancement for each building environment/zone/occupant, and the ability to relate costs and activities aiming at energy savings [9].

Past studies regarding BIM/IoT Interfacing and focused on Energy Management in O&M phase approached Energy Efficiency Awareness and Indoor Environmental Quality (IEQ) issues. Such studies attended demands from owners, facility managers, occupants, building technicians, and designers [19]. They comprised BMUs such as performance monitoring and real-time utilization to display sensor-based information collected by sensing technologies (e.g., Wireless Sensor Network—WSN), both in web-based platforms [20, 21] and BIM native environments (i.e., BIM tools as Autodesk Revit, Archicad, Solibri Model Viewer) with add-ins [22, 23]. Those applications emphasized BIM Models as persistent virtual resources for building information context, semantic relations, and 3D visualization. Furthermore, it is noticeable the potential outcomes related to assets maintenance support, since integration of BIM and IoT may provide information for preventive actions, increasing stakeholder's knowledge over the real environment [19]. In another perspective, studies such [24, 25] also exploited BIM Models to provide predictive simulation data of energy consumption for comparative purposes with actual data to improve existing operational strategies in retrofit scenarios.

82.3 Methodology

This paper is part of a research that adopted the Design Science approach, which is a prescriptive method focused on solving real-world problems [26]. It aims at describing the interface layer of a BIM-IoT prototype, emphasizing its development and partial evaluation process. The prototype's goal is integrating BIM Models and actual energy consumption data in real-time to contribute to addressing a BMU for Energy Management and Energy Efficiency Awareness issues. Based on [27] and described in the next section, the prototype's architecture embraces four layers: the sensing, network, service and interface layers.

Initially, we defined the facility managers as target users and created a feedback strategy to deliver and exhibit information with the aim of stimulating predictive maintenance and energy consumption monitoring. Then, regarding the scenario of owners that build for their own use, we considered the BIM-IoT prototype's instantiation in a building of the University of Campinas (UNICAMP). Due to the lack of a BMS at the UNICAMP campus, we developed an IoT-side solution for one research laboratory of the building. The IoT-side solution considered the laboratory's lighting system to perform a proof of concept, since [28] states that in commercial and institutional buildings the lighting and HVAC systems, as well as office equipment's are the principal sources of energy consumption. In turn, the BIM-side regarded the BIM Record Model as the primary communication channel between actual information collected from sensing technologies and facilities managers. Both sides required the following steps of the prototype's Design, Development, and Evaluation (DDE):

1. To adapt the BIM Record Model to be the primary agent of actual information delivery and display, concerning both energy monitoring and feedback strategy to attend facilities managers as target-users;
2. To input actual information collected by the IoT-side in the BIM Record Model hosted in a native environment, through a Visual Programming Language (VPL) application;
3. To implement the BIM-IoT prototype in the research laboratory to a pilot instantiation; and
4. To evaluate the BIM-IoT prototype through an analytical technique.

The evaluation step focused on verifying the prototype's performance based on real scenarios, concerning its capacity for monitoring lighting system's energy consumption as well as the interface layer role. In that sense, we considered the benefits, potentialities, and limitations of the BIM/IoT Interfacing through the created solution.

82.4 Prototype System

The proposed architecture (Fig. 82.1) consists of four distinct layers that went through two cycles of DDE. The Sensing Layer includes a WSN that is responsible for collecting, aggregating and monitoring the energy consumption data of the research laboratory's lighting system. The WSN design and development followed the OpenEnergyMonitor guidelines [29], with adaptations to attend implementation needs. The Network Layer consists of an IEEE 802.11 (Wi-Fi) communication protocol required for receiving and transmitting collected data to a Web Server (Apache HTTP Web Server). Such data is processed and stored in an associated Database Server (MySQL) hosted in the Service Layer. The Service Layer allows centralized database queries and data treatment and analysis for generating valuable information on energy consumption monitoring. In addition to MySQL, the Service Layer holds Dynamo BIM tool for extracting the latest information from MySQL Database and populate the BIM Record Model in real-time. Dynamo has the central role of enabling the BIM/IoT Interfacing and transforms the static BIM Record Model in a dynamic environment. That dynamic environment represents the connection of actual and virtual information provided by the prototype. Since Dynamo is a VPL tool that allows easy access to Revit API, we defined Autodesk Revit 2017 in the Interface Layer as the BIM tool for managing the acquired BIM Record Model. Hence, the Interface Layer contains the front-end tools for hosting both BIM Record Model and monitoring charts, the last ones available on a website. The BIM Record Model is the primary agent to display sensor based-information, comprising its delivery and display in BIM objects, schedules, and 2D/3D views. Moreover, the settings over information views regard graphical color overrides for condition monitoring purposes about lighting system's performance. Besides, the creation of an external link allowed the extension of BIM objects to the web-based monitoring charts created from the Database Server.

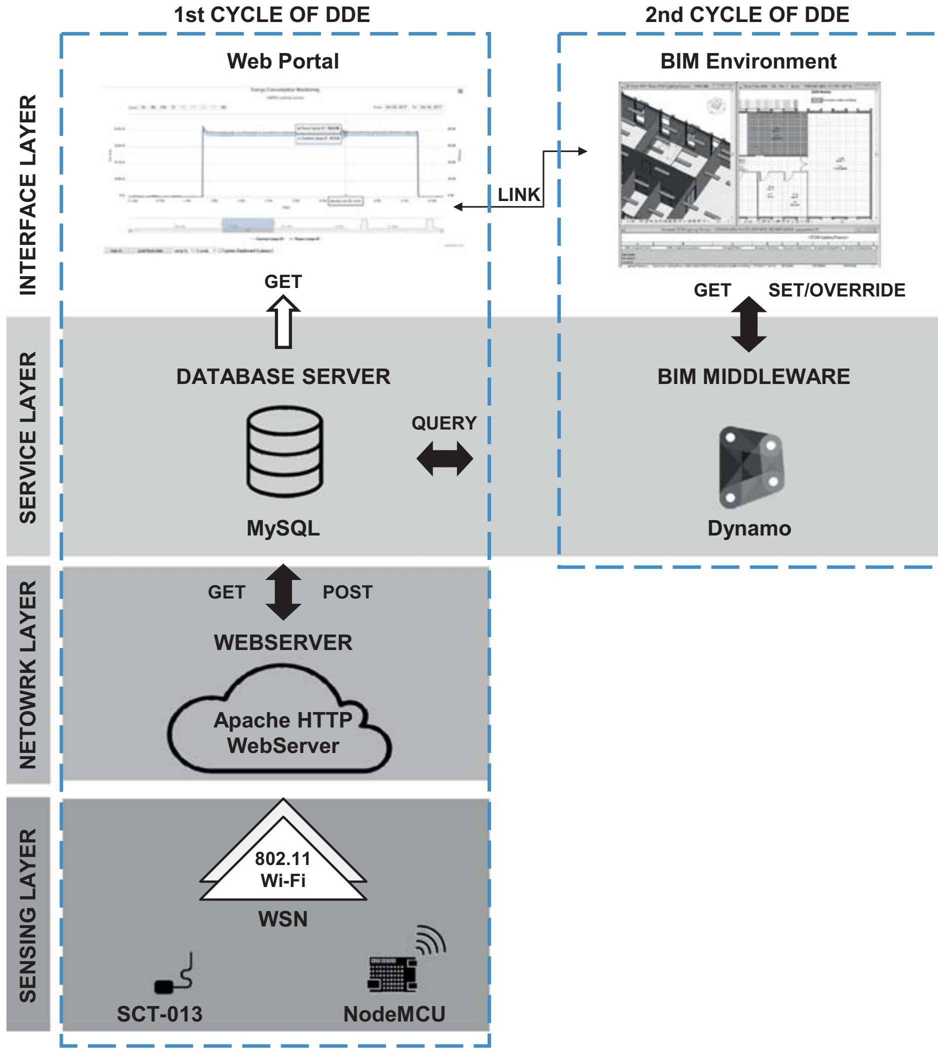

Fig. 82.1 Prototype's system framework

82.4.1 BIM Record Model and Feedback Strategy

We employed the BIM-IoT prototype in an integrated workflow, similarly to existing studies [22, 23], but with different architecture concept and definitions. The use of the BIM Record Model ensured the sensor-based information linked to building context and graphical views. The set of sensor-based information considered the user-centered feedback strategy over facilities manager's roles and responsibilities. As stated by [25] in literature and reinforced through an interview with the FM Department of UNICAMP, FM users act for monitoring and analyzing specific building performance data such as energy consumption about a particular department, zone, user, building system or time interval. The lack of BMS in the existing building of this study reflected on their activities that only involve corrective maintenance by service order and preventive maintenance. Through the implementation of a BIM-IoT solution that sup-ports building performance monitoring, the FM users may incorporate predictive maintenance in their daily practices. Therefore, the user-centered feedback strategy comprised: (i) real-time update frequency for the information delivery; (ii) desegregated (lighting fixtures, circuits or room) and historical information exhibition; (iii) reports based on condition monitoring established for lighting system; and (iv) display of multiple information units display (Watts, R$, kgCO2e/kWh) for extensive user's comprehension and knowledge.

The acquired BIM Record Model consisted of an administrative building containing research laboratories and faculty offices. The model included the accurate representation of architectural and structural systems (i.e., spaces, physical conditions, surrounding). In turn, the MEP systems were missing except for the location of the lighting fixtures. We defined one research laboratory to adjust the following BIM objects for receiving dynamic information from the database server: lighting fixtures, circuits, and rooms. Regarding the BIM Model's adequacy to the feedback strategy and 3D visualization goals, it was necessary to review the highlighted BIM objects and their attributes. The review started with the cable ducts and switches modeling, followed by lighting fixtures positioning check. Due to Autodesk Revit 2017 limitations, we generated rooms for 3D visualization with a Dynamo script. Then, we created shared properties among those BIM objects to receive dynamic information and COBie properties for assets registers to assure semantic contextualization. In addition to BIM Objects, the interface required the creation of dedicated 3D views and schedules for lighting systems' monitoring and control.

82.4.2 Actual Information Input in the BIM Record Model

Updating BIM Record Model for dynamic purposes enabled functional tests with the Dynamo script. Its programming logic initially comprised the selection and filtering of target BIM objects related to their real objects under performance monitoring. Next step involved the establishment of communication between the Dynamo environment and MySQL Database Server, through an Open Database Connectivity (ODBC) standard provided by the Slingshot! Package. It allowed the extraction of sensor-based information from MySQL, its organization in sublists inside Dynamo and its aggregation to meet condition-monitoring requirements, which were configured to generate assets reports. The final steps included the insertion of the actual information into the dynamic properties created on each filtered BIM object as well as the color override in 2D/3D views according to each asset report. Concerning condition-monitoring requirements, they admitted the operational values of each lighting fixtures, according to its specifications. For example, the lighting fixtures are according to condition monitoring considering values between 49 Watts and 64 Watts. Instead, values above or below that range indicate the demand for verifying the asset in place and possible failures in the lighting system.

It is relevant to emphasize that the actual information is a result of transformations over the collection of current data in Amperes by non-invasive current sensors. Such current data becomes active power (Watts) through the application of math formulas. The registered power data is stored in conjunction with its timestamp, which allows the application of functions in MySQL, concerning averages in a determined period or the working hours of each lighting fixture/circuit/room under monitoring. Besides, monthly averages can be applied to valuable correlations with costs and carbon emissions, enriching the feedback for facility managers.

82.4.3 Implementing the BIM-IoT Prototype to Pilot Instantiation

The research laboratory's lighting system consists of two parallel circuits (Circuit A and Circuit B) with three lighting fixtures in each one. The prototype's design to monitor the energy consumption of both circuits and lighting fixtures considered the use of a single NodeMCU microcontroller board and six non-invasive current sensors of SCT-013 family. The addition of an AC-AC adaptor assured the measurement of the actual electric voltage in real-time. A printed circuit board interconnected those electronic components (Fig. 82.2). Such implementation is also represented in the BIM Record Model (Fig. 82.3).

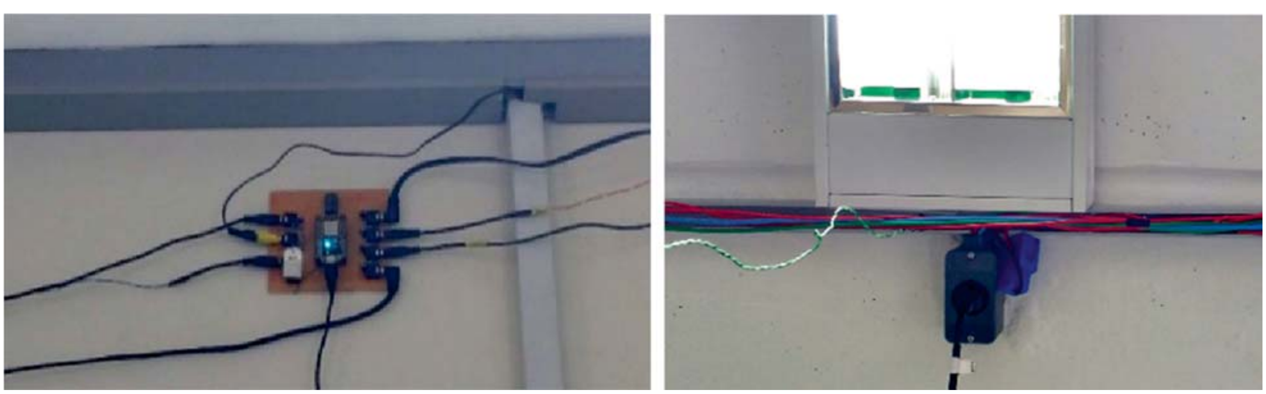

Fig. 82.2 Prototype implemented for lighting system' energy consumption monitoring

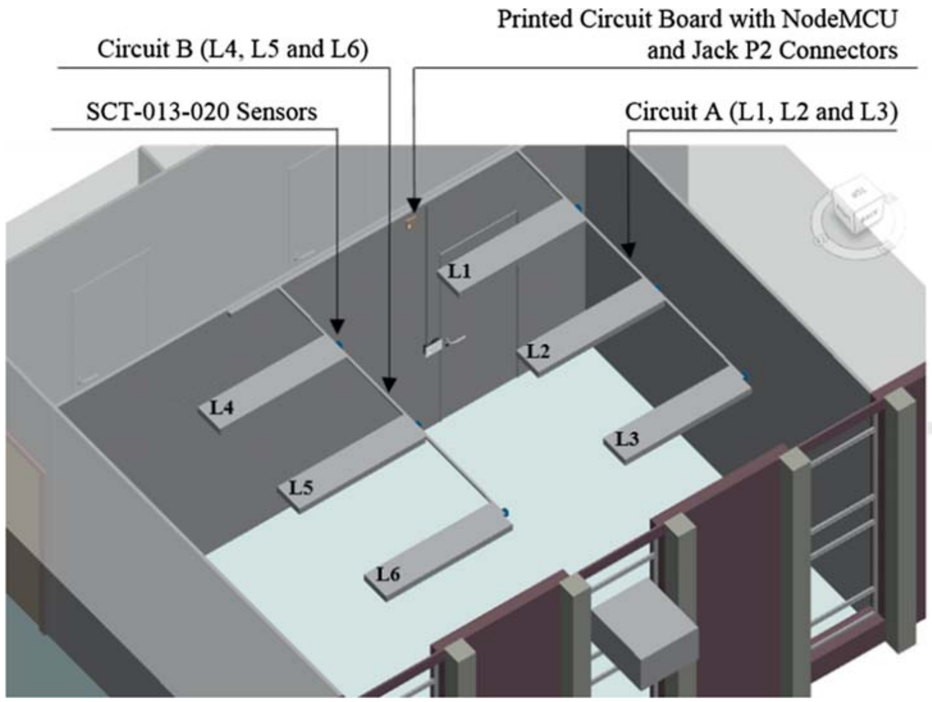

Fig. 82.3 Implementation context

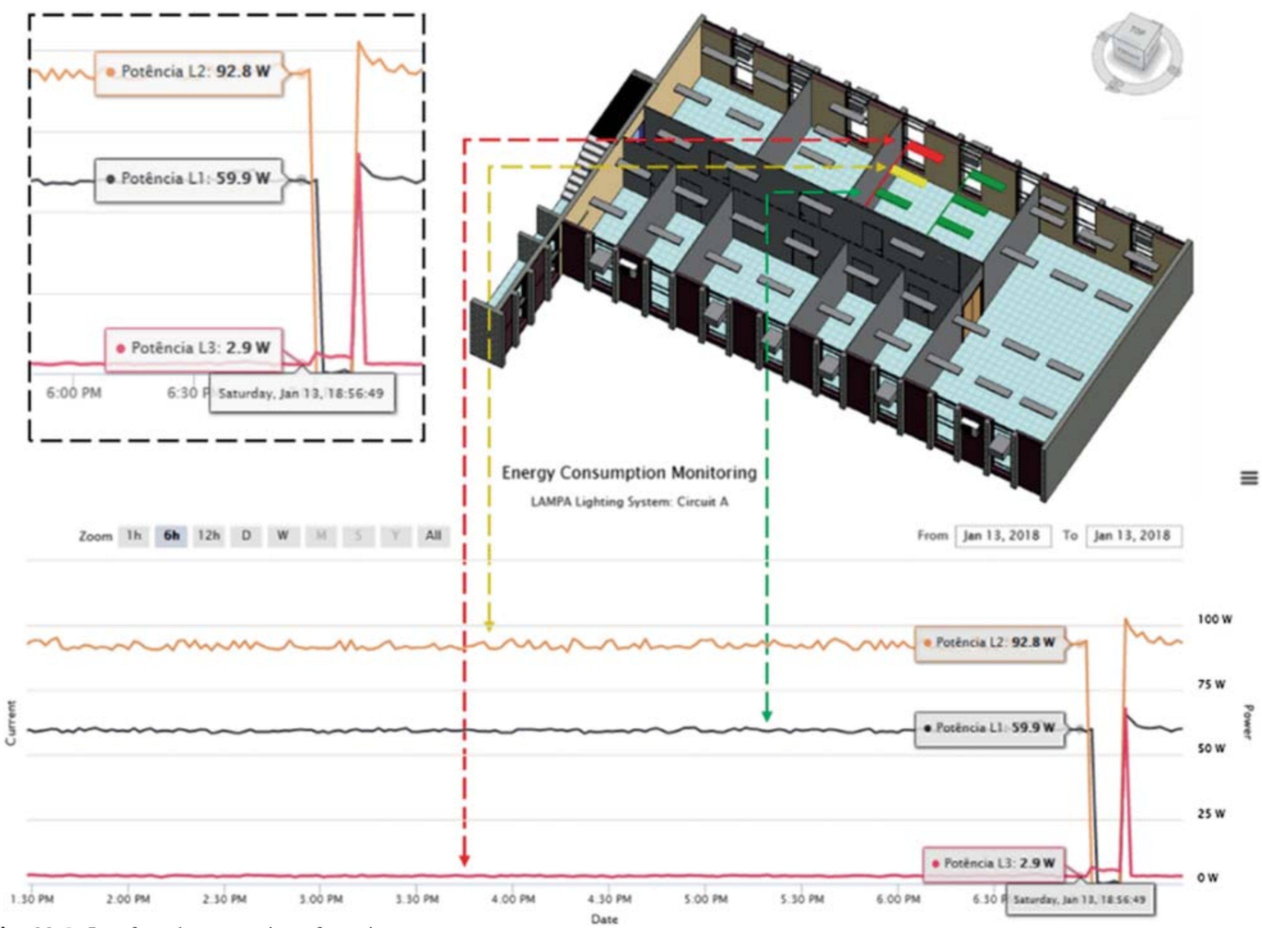

Fig. 82.4 Interface demonstration of running prototype

82.4.4 Evaluating the BIM-IoT Prototype

The BIM-IoT prototype system ran for three months for achieving monitoring results, and refining database query, Dynamo scripts, and the BIM Record Model itself. We considered populating the BIM objects (lighting fixtures, circuits, and room) with real-time power information in Watts; Watts/h per hour; Watts/h per day, month and year. Besides, for room data population we also included Cost and CO_2e/kWh properties, considering economic and environmental impacts measurement. Such information met the user-centered feedback strategy considering FM users' roles and responsibilities. Through Dynamo script, it was configured reports based on operational values, favoring predicted maintenance for building performance improvement. We presented these reports in BIM objects properties, schedules and through the 3D color overrides: red and yellow colors for "Check-in Place" and green color for "According to Condition Monitoring". Finally, we created a link between BIM objects and the external web-based charts generated from the database server. As demonstrated in Figs. 82.4 and 82.5, during the period of pilot instantiation it was possible to verify issues over condition monitoring in the research laboratory.

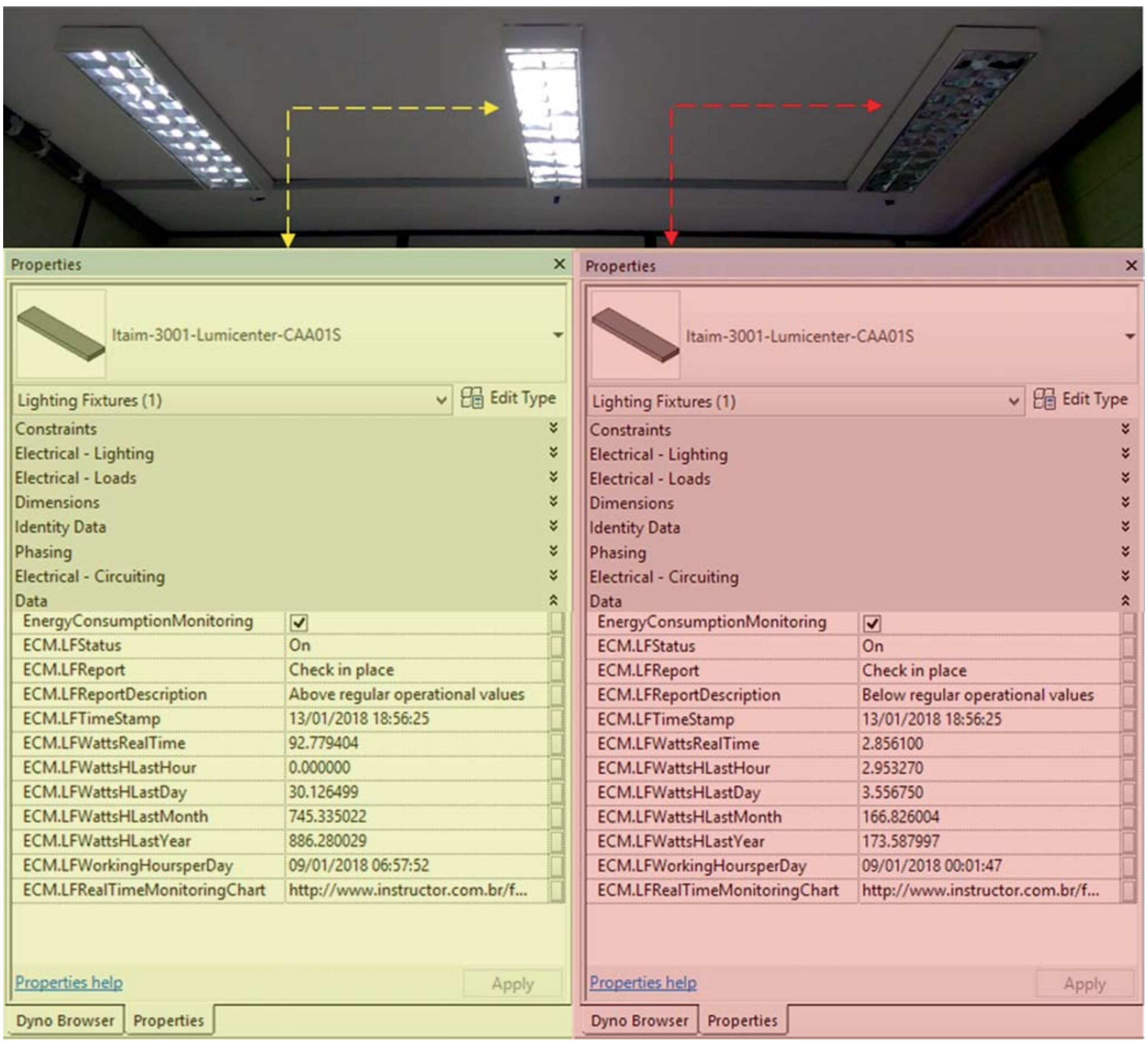

Fig. 82.5 BIM objects in record model with dynamic information: (left) LF 2 and (right) LF 3

The circuit A presented a "Check in Place" report: (i) in lighting fixture 2, power consumption was above regular operational values, which means the requirement of reviewing lighting systems' installation; and (ii) in lighting fixture 3, it was below regular operational values, which indicates performance failures and replacement demands. Monitored values could be confirmed in external charts with the benefit of historical registers, and in BIM objects properties or schedules. The evaluated scenario indicates that BIM-IoT integration plays a relevant role for increasing facilities managers' awareness on energy consumption since it acts as an accessible and interactive option for monitoring and visualizing activities.

82.5 Conclusion

This article described the interface layer of a BIM-IoT prototype, developed to promote the integration between BIM Models and building systems' energy consumption information in real-time. We highlighted by a real scenario the system's potential for monitoring the environment and stimulating building performance improvements through operational strategies of Energy Management. Prior BIM-IoT applications that employed BIM Models directly for building context and 3D views required the expertise of developing solutions in web-based or Microsoft's.NET Framework programming languages, the last ones used to create add-ins for BIM tools. Alternatively, considering the BIM Model management in a native environment, we developed VPL scripts to support the integration of BIM and IoT. In building design phase, [30] has already presented experiments with VPL, BIM Models and sensors as well. VPL demonstrated to be an accessible mode of enabling BIM/IoT Interfacing, transforming BIM Models from static to dynamic with the ability to self-update actual information. At first, that scenario emphasizes the demand for programming skills (visual or textual) when considering the development of applications that aim at BIM/IoT Interfacing. Also, that self-update ability indicates a machine-to-machine (M2M) communication trend involving BIM Models. Besides, supporting such dynamic condition, BIM Models potential extension to external databases allows the persistent connection between the real and virtual worlds.

Few before-mentioned studies presented user-centered interfaces. User's feedback on Energy Management should be appropriately structured according to building users' roles and responsibilities. We considered a feedback strategy for facilities managers comprising real-time update frequency, desegregated 2D/3D views, instructive reports as well as assets and performance registers. That strategy enriched the use of BIM Models for Energy Monitoring. Thus, BIM-IoT prototype presented itself as a feasible solution to support such strategies and provide feedback to target-users, since it acts as an accessible and interactive option in monitoring activities and supporting predictive maintenance. Regarding the limitations of this study, it is relevant to highlight the potential of BIM/BMS Link and how its lack influenced in the DDE of the BIM-IoT prototype. Also, the presented solution required BIM skills from FM team to manage the dynamic model, an unusual scenario that indicates the need for contributions regarding BIM Models in, or associated with, BMS environments.

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