44 A BIM-Based Decision Support System for Building Maintenance

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Abstract

Available data about asset condition and performances can be conveyed into different Key Performance Indicators (KPIs). Many KPIs measuring technical, functional and economic/financial asset performances can be found in literature. Nevertheless, they are often strictly related to a specific scope, thus they provide an incomplete depiction of the whole assets performances. The objective of this research is to provide facility managers and asset owners with an easy instrument to prioritize maintenance. In order to reduce costs related to its use, the instrument, developed in the form of a Decision Support System (DSS), is based on existing and reliable performances metrics and leverages new technologies like Building Information Modelling (BIM). Accordingly, the Facility Condition Index (FCI) is combined with the D index, a KPI related to the age of building components, developed by the authors. The joint use of the FCI and the D index, allows facility managers to make more conscious decisions. The proposed DSS helps in the definition of the best maintenance plan, providing a ranking of building components which require more urgent maintenance interventions. Although the DSS should be tested measuring its ability to preserve buildings and their performances on a long term, the first results are positive, as confirmed by the application to a case study on an office building in Italy. Moreover, the usability of the instrument has been appreciated by the users in a medium size Italian company.

Keywords

DSS • Maintenance • FCI • Building condition assessment

44.1 Introduction

Management of building maintenance is one of the biggest challenges in Facility Management (FM) since in this sector, nowadays, most of the economic resources related to the construction industry are spent. Additionally, a more sustainable built environment can be reached only by improving energy and environmental performances of physical assets optimizing, as instance, the maintenance choices [1].

Despite the huge amount of data produced and recorded by new technologies during the whole lifecycle of a building, facility managers make decisions on maintenance with limited knowledge concerning buildings condition [1]. Available data

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about asset condition and performances can be conveyed into different Key Performance Indicators (KPIs) [2]. Nevertheless, KPIs are often strictly related to a specific field, thus they provide an incomplete picture of the whole assets performances.

The objective of this research is to provide facility managers and asset owners with an easy instrument to prioritize maintenance, based on existing and reliable performance metrics and leveraging new technologies like Building Information Modelling (BIM). For this purpose, a Decision Support System (DSS) based on the Facility Condition Index (FCI) and service life of building components has been developed. The DSS has been integrated within the Building Information Modelling (BIM) approach and a has been tested through a case study concerning an office building located in Erba, Italy.

44.2 Background of the Research

In this paragraph the background of the research is presented, stressing on the possibilities and advantages provided by the use of an effective Decision Support System (DSS) for Operations Maintenance and Repair (OM&R) management. Moreover, potentialities and criticalities of the Facility Condition Index (FCI), one of the most acknowledged KPIs for maintenance management are presented.

44.2.1 Decision Support Systems for Management of Buildings

Decision Support Systems (DSS) are frequently used when dealing with the built environment [3, 4]. Their importance lies in the possibility of comparing multiple features, computed both through subjective and objective parameters and calculation methods. DSS weaknesses generally include: the high influence of the weights used, the reliability of the parameters calculated and their need for large amount of data to be gathered and elaborated in order to produce reliable results. In general, they should be used in the early project phases, although their precision is higher when more data are available (and less changes are possible).

DSS can be based on several data processing techniques though, usually, they are all based on Multi-Criteria Analysis Techniques, which allow data normalization, elaboration, comparison and eventually, alternatives' ranking and selection.

A robust method, frequently used in association with a DSS [5], is the Analytical Hierarchy Process (AHP), which allows for parameters weights calculation. The method was first proposed by the mathematician Saaty in the 80s [6] and is frequently and successfully coupled with the Delphi method, no matter the topic, in order to enhance the quality of the weights calculated and achieving more precise results [7].

Another issue to be faced in the development of a DSS concerns the connection with the data to be gathered, the less work needs to be done, the faster will be the analysis, thus the connection with the BIM processes [8], can enhance a better information flow.

44.2.2 Facility Condition Index

The Facility Condition Index (FCI) is a metric widely exploited for assessment of assets [3], thanks to its scalability from the single component to the whole real property [9, 10]. Therefore, it is a powerful tool which makes assets comparable in measures of maintenance performances. In its basic form it is used for evaluation of costs of deferred maintenance (DM), over the Current Replacement Value (CRV) of the component [11]. The FCI allows to quantify in a scale from 0 to 100 (where 0 represents the best value) the condition of an asset based on the expense dedicated to maintenance operations [11]. The assessment phase is a crucial issue for the calculation of the metric. Nevertheless, the calculation methodology can vary according to the objective to be achieved [12]. Moreover, a standardized definition of algorithms to be used cannot be found in literature [13].

The FCI is affected by some other issues. For instance, the ratio calculated through the indicator does not represent the magnitude of the DM interventions, since the output value is mainly influenced by the CRV. For this reason, the FCI calculated for two similar components characterized by similar deferred maintenance interventions (with analogous cost), could be affected by substantial differences according to the value of the CRV. Accordingly, the FCI should be employed along with other indicators and coefficient, able to balance the effect of the CRV and to grasp the strategic importance of a component [14, 15].

44.3 Research Methodology

Building Information Modeling (BIM) can be considered the cornerstone of research in construction field in recent years [16, 17] and it is widely acknowledged that asset owners will gain considerable advantages from a comprehensive Asset Information Model (AIM) furthering the strategic framework for asset management [18]. The AIM, as defined in BSI PAS 1192-3:2014 [19], is the foundation of the proposed research methodology that can be described by two main steps:

1. the transition from the physical asset to the digital asset, namely the AIM;
2. the maintenance operations prioritization through the DSS, reading data from the AIM.

The first phase of the research (Fig. 44.1) consists in the creation of a template for the development of BIM models of existing buildings. The survey and the digitization of the building and its surroundings can be expensive issues [20], which frequently prevent the adoption of BIM processes for management of the built environment. Therefore, a BIM model characterized by a low level of detail, which can be incrementally upgraded during operation, has been developed. This choice allowed to create a model with approximately one day of work, starting from as-built CAD drawings and carrying out a streamlined survey of the asset and its parts. The BIM template must be constantly updated, to automate some activities and to improve the quality of the output. The BIM model has been developed, using Autodesk Revit, connecting the building objects to a specific phase of the management process, so to create a depiction of the asset status at a specific date. The model, intended as geometrical objects and information associated to them, can be considered the digital twin of the physical asset and is used, in this case, for maintenance prioritization. This approach can ease the building maintenance operation, reaching higher levels of automation in maintenance management process [21].

The data contained in the BIM model are associated with data coming from an external source, namely the maintenance costs database (DB). The maintenance cost DB is based on the Uniclass II standard [22]. This classification system has been used to define the minimum level of breakdown of the building, that would allow an effective association with maintenance interventions and costs. Costs of maintenance interventions and components' replacement values have been defined employing the Milan's Municipal pricelist [23]. From a methodological point of view, this allows to define a standard set of building components associated with maintenance interventions and cost, though a case-by-case analysis has to be carried out when the methodology is implemented.

Once the standard maintenance cost DB is defined, the Building Condition Assessment (BCA) survey phase can start. Through the BCA campaign, deferred maintenance interventions as well as the related costs are identified. Survey results are stored in the BIM model created following the bespoke BIM template that allows an easy data extraction by the DSS Dynamo script (phase 2).

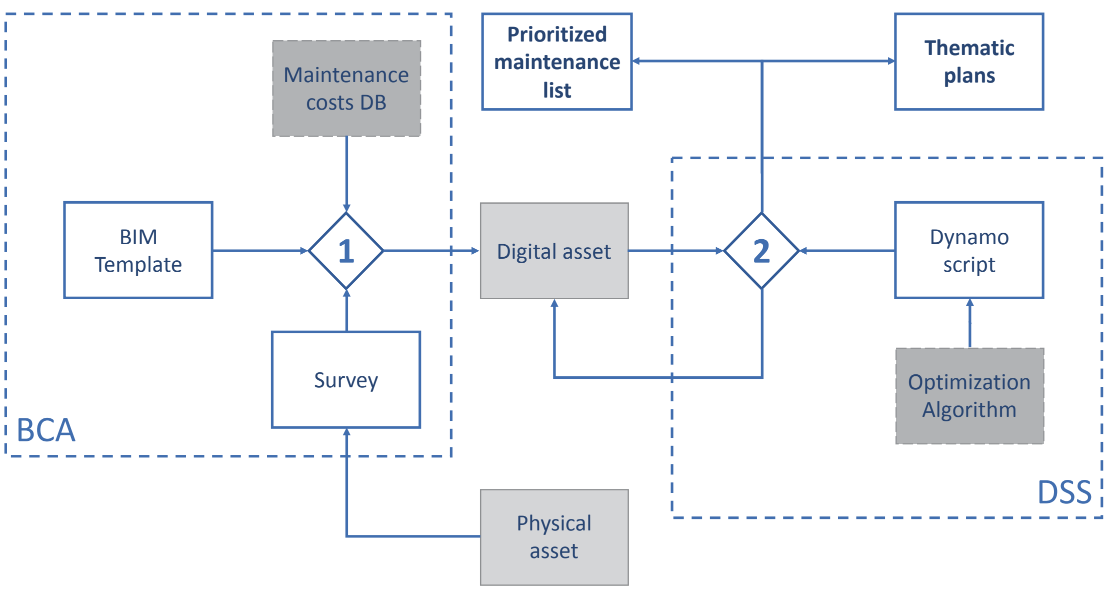


Fig. 44.1 Research schema

Among the information stored, the one related to building components' service life are of primary importance for the prioritization algorithm. Reference Service Life data are stored in the IFC2X4 property set named *Pset_ServiceLife*. This property set was introduced with the version 4 of the (Industry Foundation Classes) IFC standard [24] as a replacement of *IfcServiceLife* and is applicable to every *IfcElement*. For the purpose of this research, two are the property of the *Pset_ServiceLife* used: *ServiceLifeType* and *ServiceLifeDuration*. The first one describes the type of value stored in the *ServiceLifeDuration* property, it allows for 5 types of *IfcPropertyEnumeratedValue* and the only one used in this research is "REFERENCESERVICELIFE", i.e. the typical service life that is quoted for an artefact under reference operating conditions [25]. The *ServiceLifeDuration* property contains the *IfcDurationMeasure*, namely the length or duration of a service life [25]. The actual service life is not stored in the model since it is calculated by the Dynamo script from the *InstallationDate* value provided by Construction Operations Building Information Exchange (COBie) [26] information.

Once the data are available, it is possible to run the algorithm, obtaining two types of output: the list of prioritized maintenance operations and graphical representations, e.g. thematic plans and 3D views.

44.4 DSS Development

As stated in paragraph 44.2.2, FCI gives better results when combined with other KPIs for maintenance operations prioritization. The developed DSS is based on a combination of two KPIs for each component, the FCI and the D index: a metric that measures the service life of the component. The D index is derived from D^+ and D^- indexes developed by Dejaco et al. [27]. Since only two parameters are used in the DSS, no weighting system has been used, therefore the AHP method has not been applied.

The D^+ and D^- indexes cannot be used in their original form because the authors used respectively two different calculation methodologies, according to the age of the components, compared to the Reference Service Life (RSL). Moreover, although the two indexes are limited between 0 and 1, they work exactly the opposite way the FCI works, namely higher values indicate a higher performance. Thus, the D index employed in the DSS is computed with the same parameters defined by Dejaco et al. [27] but in a slight different way: starting from 0 when the component is newly installed, the D index increases when the component gets old (see Eq. 44.1).

$$D = \begin{cases} \frac{asl}{rsl} \times \frac{1}{2} & if \quad asl \leq rsl \\ \frac{1}{2} \times \left(1 + \frac{asl - rsl}{asl}\right) & if \quad asl > rsl \end{cases} \tag{44.1}$$

where

- *asl* is the actual service life of the component, i.e. the time span from when the component has been installed or built, until now;
- *rsl* is the reference service life of the component [28].

Equation (44.1) shows how the D index is computed with two different equations according to the age of the component. When the actual service life of the component is lower than its reference service life, D ranges from 0 to 0.5 and is calculated likewise D^+ by Dejaco et al. When component actual service life is bigger than the reference one, i.e. the component is too old, D ranges from 0.5 to 1 and is computed similarly to D^- by Dejaco et al. Noteworthy, in D index the value 1 is an asymptote, like it is 0 for D^-. Figure 44.2 shows how the D index varies with the actual service life of a component that has a reference service life of 25 years.

The proposed DSS contributes in easing informed decision-making through a graph where on the X axes is plotted the FCI of the component and on the Y axes the respective D index. This kind of graph allows to identify three areas delimited by two ellipses (Fig. 44.3):

- the critical condition ellipse: is an ellipse with the major axis parallel to the Y axis and passing through two points C_1(0.10, 0) and C_2 (0, 0.50). Noteworthy, 0.10 is the FCI threshold for critical component (C_1) and D = 0.50 means that the actual service life of the component is equal to its reference service life;
- the poor condition ellipse: is an ellipse with the major axis parallel to the Y axis and passing through two points P_1(0.05, 0) and P_2 (0, 0.25). It may be highlighted that 0.05 is the FCI threshold for poor component (P_1) and D = 0.25 means that the actual service life of the component is half of its reference service life.

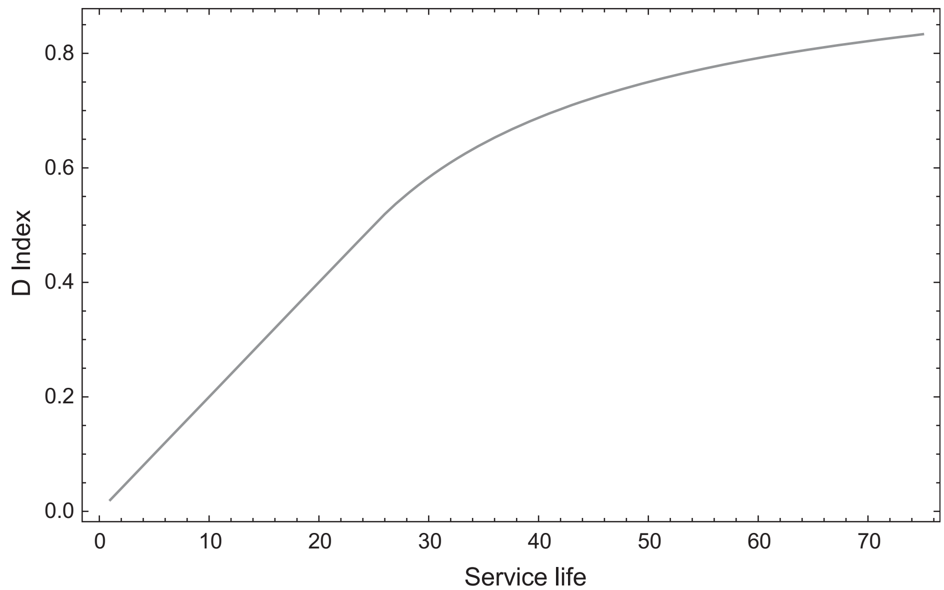


Fig. 44.2 Diagram of the D index for a component with RSL = 25 years

Other important information given by the DSS is the distance of each point (representing a component's condition) from the critical or poor ellipse. The bigger the distance the greater the need of maintenance of the component. Components in critical or poor condition are classified in 5 severity classes (Fig. 44.5), according to the distance from the boundary ellipse, either critical or poor. Decision makers can then focus maintenance budget for components that actually need more urgently maintenance.

44.5 Application of the DSS

To validate the proposed approach, a demonstration on an office building near Como (Italy) was carried out. The asset, built in 2006, is currently occupied by a construction company and a notary firm. It consists of one underground and three stories above ground (around 1000 m^2 of gross surface per story). According to the proposed methodology, the BCA has been carried out and the maintenance cost DB has been developed and adapted to the building under analysis. Figure 44.3 shows the condition of each component analyzed, highlighting that there are objects that may need maintenance even if their FCI is lower than 5%, since they are close to their reference service life (D = 50%) or even above. Among these latter, some parts of the mechanical system are very well maintained (FCI = 0%) but too old (D > 50%).

Structural components surveyed are characterized by a very good FCI (an average of 4.29%) and a very low D (around 8%), since the building is quite new. Although, most of the components are in critical conditions, as can be seen in Fig. 44.4, and 30% of the analyzed elements are in poor condition. If the budget for maintenance is not enough to intervene on all critical and poor components, the one on which resources should be spent can be identified by measuring the distance of each point from the boundary ellipse (Fig. 44.3).

To help decision makers, the distances from the boundary ellipse of critical and poor components have been classified according to five severity classes. Figure 44.5a shows that most of the critical components are in the first severity class (the less critical) and only one component among the critical ones is in the most severe condition (Severity 5). Figure 44.5b shows that most of the poor components are in the intermediate class of severity (Severity 3) and none is in the most severe one (Severity 5).

In Fig. 44.6 the BIM model of the case study is presented. Results computed through the DSS are stored in a custom property set called "MaintPrior". In Fig. 44.7 the property set filled with the values computed for the roof of the building is shown.

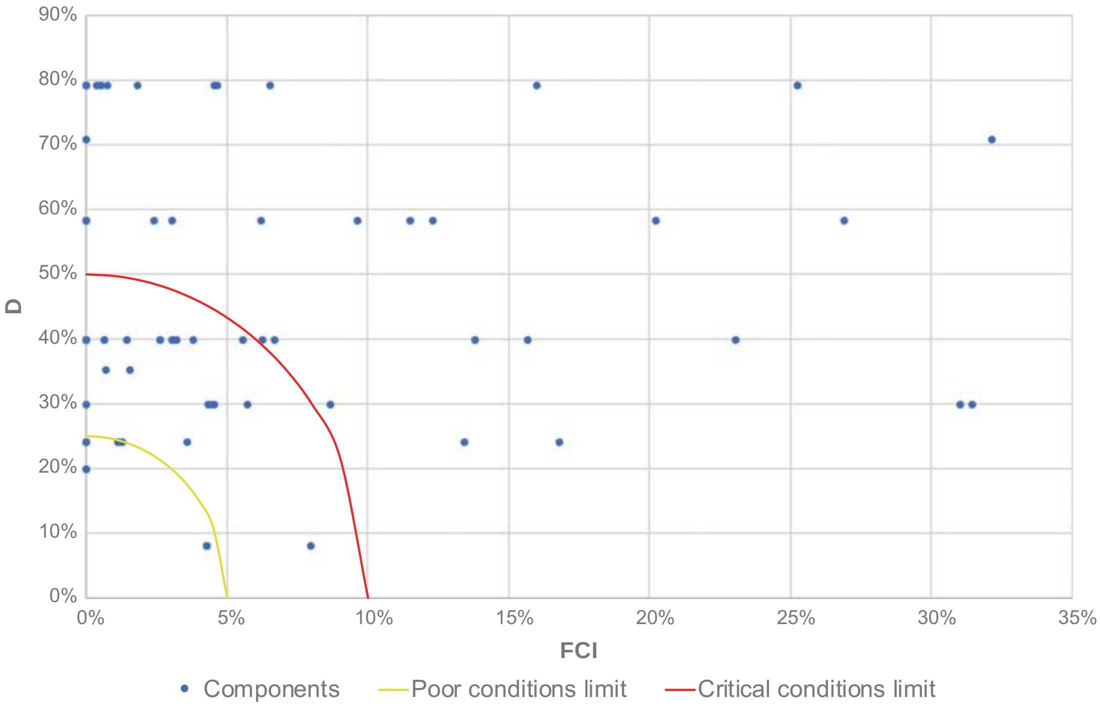
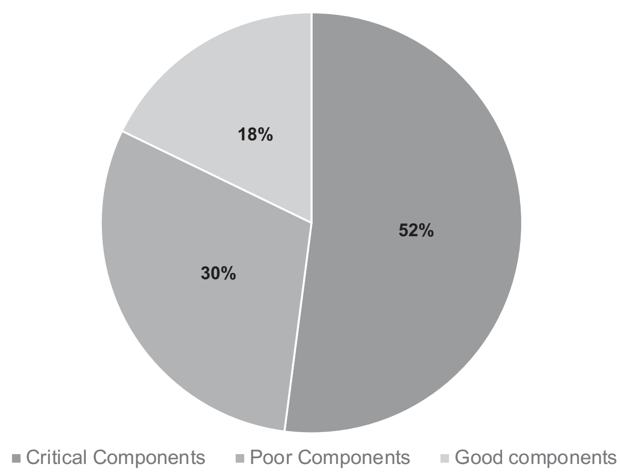


Fig. 44.3 Components condition

Fig. 44.4 Percentage of components in critical, poor and good condition



44.6 Discussion and Conclusions

Asset managers must often make decisions about maintenance and renewal alternatives based on sparse data concerning the actual assets' condition [29] wasting, as a consequence, a huge amount of economic resources. Thus, a DSS easing the prioritization of maintenance operations has a great importance for asset owners. The proposed DSS, based on two KPIs, the FCI and the D index, classifies building components according to their need for maintenance interventions. The use of the D index helps in overcoming the limitations of the FCI. The proposed DSS has led to good results in the case study, although some drawbacks still have to be addressed. For instance, the method does not take into account the cultural or historic value of the asset, the asset owner's peculiar requirements or necessities and the intended use of the building. Despite the limitations, the usability of the tools has been appreciated by the firms appointed for maintenance management of

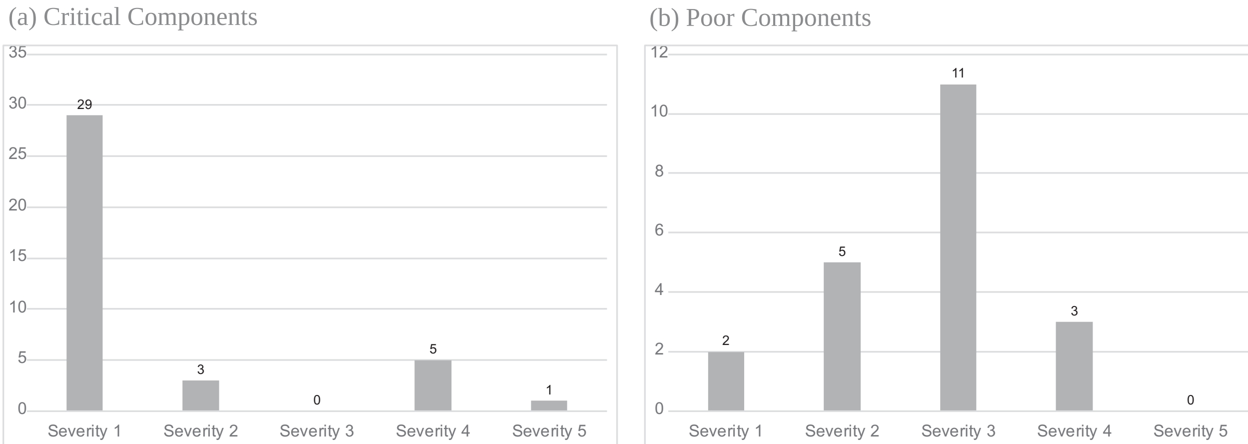


Fig. 44.5 Severity of the condition of components in critical (**a**) and poor (**b**) condition

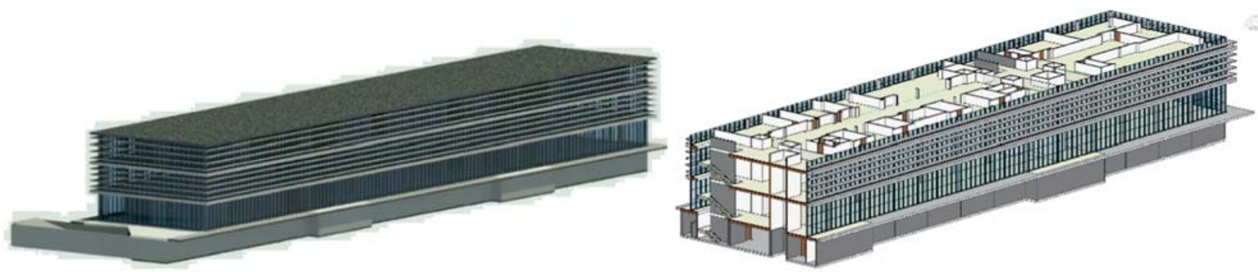


Fig. 44.6 BIM model of the case study

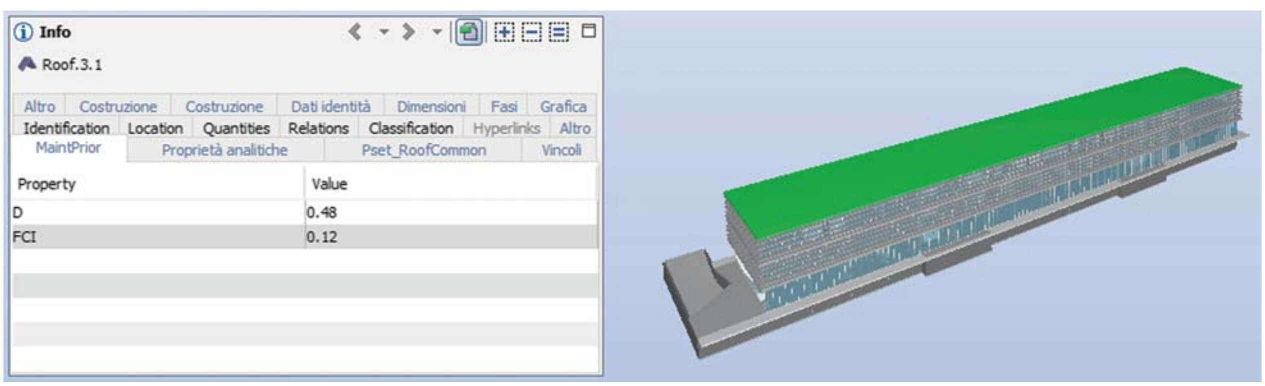


Fig. 44.7 Custom property set

the office building in Erba, Italy, on which the case study has been carried out, mainly because the DSS leverages semi-automated BIM processes to save and retrieve data. The future research work will be focused on widening the scope of the DSS, through the integration of further KPIs according to specific clients' needs and according to specific building types. Moreover, the DSS will be further integrated and automated within the BIM approach.

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