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HBIM AND FIRE PREVENTION IN HISTORICAL BUILDING HERITAGE MANAGEMENT

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Abstract

Italy possesses a unique cultural heritage that is constantly under threat from natural and anthropic risks: fire vulnerability is one of the main causes of architectural heritage destruction.

The goal of this work is to propose a methodological approach to the management and preservation of historical building heritage with respect to fire safety. This approach aims to facilitate the process of analysis, design and fire management in historical buildings, using automated procedures based on HBIM (Historical BIM) processes.

BIM can be used effectively in the digitization of cultural heritage: HBIM enables the three-dimensional modeling of the building by means of parametric objects, to which infographic information is associated, related to an appropriate Level of Development (LoD).

A workflow process has been defined to set up a procedure for best practices which can guarantee the correct interoperability between BIM programs and fire safety design.

The procedure, based on the exchange of IFC files, shows result applying analysis through Model Checking software of Model Checking and shows limited interoperability with fire safety software. The procedure has been validated through real tests and measurements, by comparing data obtained from a traditional fire prevention analysis with the data gathered from the automated procedure.

The real case study is the “Command Building” of the School of Air Warfare in Florence. Results mainly indicate that fire safety in historical buildings should always be managed using a performance-based approach (interoperability issue between HBIM and fire safety software).

Keywords – HBIM, interoperability, fire safety, historical buildings.

1 Introduction

In the past a high number of fire events, with serious consequences in terms of damage, have occurred both in Italy and abroad. The knowledge of these events and their analysis is an important source for their prevention and for the identification of specific guidelines to improve standard safety conditions. In order to protect historical building heritage it is useful to define a methodology based on an integrated digital design procedure aimed at fire safety management.

One possibility could be to use BIM (Building Information Modeling) and interoperable procedures, not only to coordinate the project during the whole building process, but also to obtain numerical data by analysing the virtual model through specialist simulations [1,2,3]. In fact, Building Information Modeling has been used for years during the renovation and restoration phases, also through collaborative platforms for the "design" of existing buildings (HBIM) and with different aims [4,5,6]: the virtual model can be used as a tool to highlight criticisms in the existing fabric and drive the decision making process [7].

This article sets out an approach for improving the interoperability between HBIM models and open source software for fire prevention analysis, validating the procedure through a comparison between the results achieved by the automated procedures and those derived from a traditional analysis.

The reported case study, the “Command Building of the School of Air Warfare” in Florence [8], deals with a building that belongs to Italian artistic and cultural heritage. The main purpose of this study was to evaluate the use of BIM for historic buildings and, specifically, the possible correlation between the process of fire prevention and design.

Figure 1. The Command Pavilion, aerial photo [8]

2 State of the art

The eBIM (Existing Building Information Modeling) and HBIM (Historical Building Information Modeling) focus attention on a different design process to the one applicable to new buildings, but at the same time guarantee the database definition of various info-graphic information capable of transmitting specific meaningful content [9]. The model assumes significance not only as a geometric representation of the architectural object, but rather as a database for all the data collected during the survey phase and construction analysis [2,10].

In contrast to the modeling of ex-novo artifacts, where the parametric entities (BOMs) that define the model are collected within BIM platforms, in a cultural and historical building the definition of the "Historic Building Object Models" (H-BOMs) is subjected to a survey phase, which must possess specific features for the development and management of historic building models [5,6]. The difficulties of implementing projects for historical building heritage are not only related to the definition of new architectural elements that complement the existing database, but also to the need to define a Level of Development (LoD) as a function of the analysis that is going to be performed. In that sense, it is possible to calibrate the quantity and quality of necessary information and avoid time-consuming procedures during the reconstruction of the monument under analysis [5].

Also in the field of Fire Prevention an integrated approach based on BIM technology is useful, aiming to guarantee the interoperability between BIM software and specific software packages aimed at the planning phase and/or at fire testing [4,11,12].

From the fire safety point of view, in order to protect the buildings and their contents it goes towards a performance-based approach and it's therefore able to adapt the design solutions to the reference building context. This is a very important aspect for fire prevention and for protecting historical and artistic heritage, in which there is considerable difficulty in applying the rules, codes and prescriptive regulations: the identification of *ad hoc* solutions to this case makes it possible to reach a level of safety for buildings equivalent to that regulatory ensuring a lesser impact on the structure and convenient economic implications [13,14]. Nowadays there is a wide range of software, for example CFAST and FDS [13,15], that can both simulate a fire in order to determine the spread of fire and smoke, the response of a building at high temperatures and the movement of users leaving the building, and check the regulatory requirements concerning divisions and escape routes.

The development of this software provides high design flexibility and the opportunity to analyse aspects related to both the protection of human life and the protection of artistic goods [13,16].

3 Methodology

The main issues related to the historical heritage of artefacts relate to management as a whole; an important aspect is the fire vulnerability of structures which are sometimes subject to a functional change (such as office buildings, hotels or hospitals) with the inclusion of activities which do not provide specific rules for these types of buildings.

The use of an HBIM approach, still to be finalized, makes it possible to address the problem of the management of historic buildings by allowing interoperability between the software in order to facilitate the exchange of information in a digital format.

It is therefore essential to define from the outset the level of detail desired, so as to calibrate the information necessary for the realization of the various parametric objects that will compose the model. Once the HBIM model is completed, we propose an approach to fire prevention analysis by performing the relevant checks with a validation software program, such as Solibri Model Checker, to identify problems and/or design errors. Parallel analysis was carried out with traditional techniques to have a parameter for comparing the obtained results.

4 H-BIM and LoD

Applying the HBIM techniques means applying different approaches that can change in accordance with the building typology and its cultural relevance (for instance, if the building is a monument and if it has a certain aesthetic and architectural value) [5]. The BIM model has to be modelled with a certain LoD that must be chosen in accordance with the final purpose of the model. Possible purposes are discussed in the following list

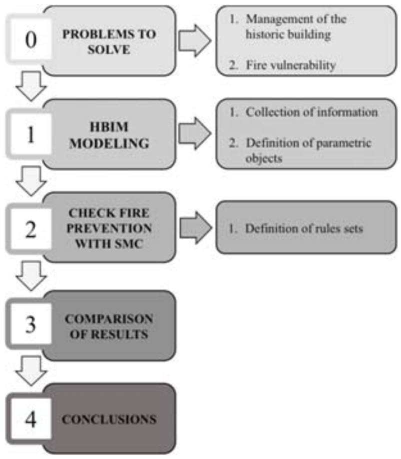

Figure 2. Scheme of the proposed method

1. architectural restoration for the preservation of historical heritage through the simulation of conservative, supplementary or reconstructive assumptions and the creation of a visual data-base where they are collected, and the various preliminary investigations, contextual and post intervention;
2. recovery and reuse interventions in order to restructure and retrain the existing buildings, possibly by proposing a change of intended use;
3. structural analysis aimed at the rehabilitation of existing buildings through local interventions, adjustment or seismic improvement;
4. upgrading of plants through energy design;
5. to design facility management interventions aimed at the ordinary and extraordinary maintenance of buildings, of safety in the workplace and of fire prevention.

In the case of renovation projects and/or restoration of existing buildings, the experts involved are almost always forced to create new elements reproducing the objects belonging to the building's historical repertoire that complement the existing database.

Our methodology refers to Common BIM Requirements [17,18] that describe the requirements for the implementation of a BIM model, both in relation to data collection procedures and info-graphic modeling. In the case of existing or historical buildings, series 2 [18] describes how to start with an "inventory model", understood as the modeling of the state of information quality related to the building at the time of the recovery and/or restoration project. The COBIM identifies three methodologies for data collection which involve the use of specific tools that are not always available; therefore, this highlights the need for a new classification that includes printed material about the original design. The means for the reconstruction of an existing building, through a BIM model, can then be listed in the following way:

- Level 0 - Original documents and archival sources;
- Level 1 - Laser distance meter and total station;
- Level 2 – Photogrammetry;
- Level 3 - Laser Scanner.

For each of these levels, it is possible to associate a “precision degree” and an “information accuracy”, which can influence the precision of the overall BIM model.

If we refer to the lowest level of accuracy, Level 0, the precision of the BIM model is connected to subordinate to the graphic errors and tolerances expressed by the source documents. For instance, if the document is represented with an architectural scale of 1:200 and the elements are represented with a weight line of 0.2 mm, the error can be quantified as 4 cm and the tolerance is expressed around 4/10 cm. To drastically reduce this inaccuracy, it is necessary to integrate the historical sources with a direct survey and, even better, use photogrammetry and a laser scanner. Figure 3 shows the relationship between the degree of accuracy and the representation error derived from the different methods used to perform the survey.

Figure 3. Relationship between error of representation and level of accuracy of different data collection techniques of a BIM model.

When there is the need to create an HBIM model it is therefore essential to obtain a sufficient amount of geometric and topological information, qualitatively suitable for the reproduction of each construction element that characterizes the object of study: the more data available to the designer, the more the result will correspond to reality.

Often the choice regarding the use of the best available technology for survey (i.e. the laser scanner), which involves minimum representation errors, is not always the most appropriate solution: the degree of accuracy provided by each data collection methodology is closely related to the objectives which must be achieved. Depending on the purpose for conducting the survey, and the reference scale representation with which the measured material is to be processed, it is clear that direct detection methods can be used, bearing in mind the increase of possible errors that may occur. An accuracy level of the detail needed for the reproduction of the building is associated to each specific purpose of the survey realisation. Therefore, we can find three categories:

- High detail level of accuracy, which requires an almost realistic representation of the object;
- Average detail level of accuracy, in which the loss of precision does not create excessive problems;
- Lowest detail level of accuracy, for which a less detailed reproduction of the components of the object is sufficient.

In parallel, according to the type of representation that is needed (and is possible to obtain), each level corresponds to the most appropriate type of tool, considering advantages and disadvantages resulting from its use.

The higher the level of detail required, the greater the degree of achievable accuracy with which the survey must be performed.

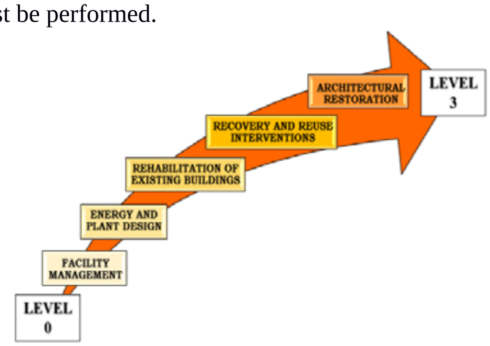

Figure 4. Relationship between a survey proposed for historical-monumental buildings and the level of accuracy obtained with the different methods.

5 Risk assessment through BIM processes

Although there is a lot of fire simulation software, in existing buildings a traditional approach to fire prevention is still one of the most commonly-used methods.

The implementation of risk assessment through BIM methodology allows a simplification of procedures between the design and the analysis, avoiding the need to refer to paper material or CAD files which allow the passage of a small amount of information that is mostly related to dimensional data. Starting from a BIM model and designed with an appropriate LoD for the preparation of a preliminary evaluation aimed at fire events, the user may be able to develop the necessary evaluations which can handle not only the geometrical aspects of the construction but also all the data related to the intrinsic properties of the materials. The main applications for fire safety verification adopt the IFC standards as a tool for interoperability, for the sharing of design information, but there are still issues related to compliance with the interoperability standards adopted by various implementation software programs and by intrinsic conformity to the IFC model that always needs integration.

6 Case study: the "Command Building" of the School of Air Warfare in Florence (Italy)

The proposed case study involves the application of BIM technology for the "Command Building" of the School of Air Warfare in Florence, one of the most avant-garde architectural and engineering masterpieces of 1930s.

The construction began in 1936 with the arch. Raffaello Fagnoni, who was commissioned to build the "Application for the Royal Air Force School", now the "Institute of Military Aeronautical Sciences" [8].

One of the buildings that is part of the School of Air Warfare is the Command Building, where office activities take place: the exception is the top floor where there the apartments of the Commander are located. The building looks like a compact parallelepiped with a square plan that essentially consists of two parallel buildings placed in an east-west direction, connected to each other by two transverse bodies, realized with characteristic Vierendeel beams, that on the top floor open into a loggia. The case study can be summarized in three steps:

1. Modelling of the building according to the principles of HBIM;
2. traditional fire prevention analysis by checking the rules on fire prevention and later defining the possible intervention solutions;
3. application of specific software (Solibri Model Checker), to evaluate the fire safety of the building.

7 The modelling phase with Autodesk Revit Architecture

In this case study Autodesk Revit Architecture 2015 was used, as one of the possible parametric software programs for the construction industry based on the BIM platform for the modeling of new and historic buildings.

The "construction" of the Command Building began with the reconstruction of maps of various levels using AutoCAD in order to have a frame of reference from which to begin the modeling. Subsequently, through the analysis of the topological information of the various technical components the appropriate families for walls and floors were defined, thereby obtaining a first and schematic project.

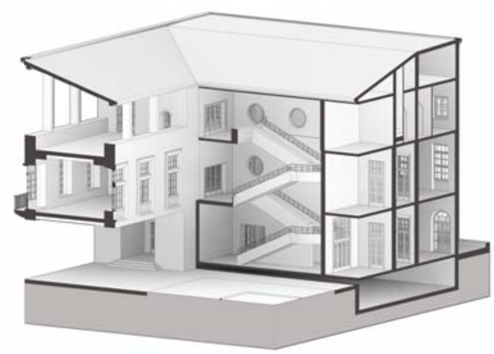

Figure 5 .Axonometric section of the Command Building.

Following this, the model was gradually refined with "in-place" family, representing the various internal and external fixtures, stairs and all the architectural elements that characterize it. An identification code was assigned to each architectural and/or structural component, generally composed of four parts:

1. generic item category and its location;
2. material and/or type of element;
3. characterizing size (for example, the thickness of walls and floors, or size for fixtures);
4. finishing material.

Proceeding in that way, by a simple request to the software, it was simple to go back immediately to family and type of each technical element that compose the building. It is important to consider that the preliminary realization of the 2D project occurred through a survey the paper material available without having the possibility to execute a direct validation of the building. This certainly implies a very high degree of approximation, directly proportional to the error of the representation expressed in centimetres. Compared to the actual size of detected objects, bigger mistakes will be tolerated on small scales, and smaller errors on big scales. Despite being in possession of limited and not very detailed information, it was possible to reconstruct the building in order to perform assessments on the fire safety of the structure.

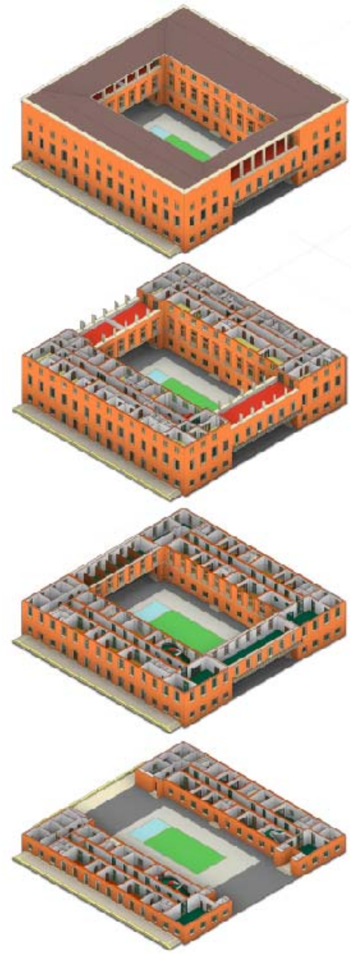

Figure 6. 3D building.

8 Solibri Model Checker

Solibri Model Checker (SMC) is a software for "model checking" that allows the analysis of models through rule sets [19]. SMC is able to open both .dwg and IFC files: the hierarchical structure, the topological relation between elements and their dimensional and material characteristics are automatically recognized by the software. The SMC software applies a "Quality Assurance" process for each element (for instance, data of the project, products and components, services, management, production and control processes) by verifying the element's compliance with specific requirements by means of pre-set rules. The user can create customizable rules and run specific analyses in accordance with regulatory requirements, which can vary for each country.

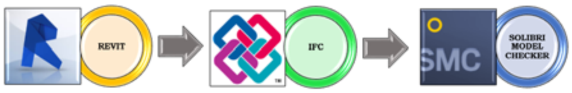

Figure 7. Export process of the Revit model on Solibri Model Checker.

These rules can be employed for the evaluation of the quality of the model and for the interference checking that makes it possible to highlight criticisms and shortcomings of projects, contributing to their validation. Among the rules proposed by SMC software is a set concerning the checking and control of escape routes. The system uses a sophisticated algorithm to identify all the possible escape routes, calculating their length: this is then compared with the user-entered limit and defined by a specific legislation. At the same time it is also possible to analyse the fire compartments, through a check on the various building components, and the minimum dimensions of the doors that define the various spaces. In this way, it provides a secure method to ensure the safety criteria for a proper fire design. Since the primary purpose of the case study is the evaluation of fire safety, we can identify three sets of control rules within the Architectural Checking "package":

- BIM VALIDATION - ARCHITECTURAL: set of rules that includes laws to generally validate the BIM model by means of audits of all structural components;
- GENERAL SPACE CHECK: rules for the setting controls on the minimum surfaces of the environments' space.
- EGRESS ANALYSIS: set of rules that control the fire compartments and the building escape routes.

In this way, the program identifies a number of actions to be taken in order to refine and detail the model. The software automatically suggests adding missing data, if not previously defined in the BIM software. The analysis begins with the classification of the doors between Internal Door, Exit Door or Balcony Door, and vertical connections between Lift, Ramp or Stair. A data consistency check of the various construction elements is automatically given by the software, verifying if the elements are classified in accordance with the IFC standards. It is necessary to associate the corresponding classification to the walls and to the exterior doors, as SMC automatically associates functions of internal elements with these.

The next step is to assign the corresponding intended use for each space detected (IFC space) distinguishing between: office, storage, residence, space group, elevator, technical, vertical and horizontal paths (circulation).

As a last step, the compartments must be defined according to various methods by choosing the most appropriate in this case, specifying the maximum area laid down by legislation. Last step for the rules-et "Egress Analysis" approach is the definition of the parameters for the escape routes: according to the classification of the various rooms, you set the maximum path length, the minimum acreage for each occupant and the point of from which to calculate the escape route. It also needs to specify the methodology for measuring horizontal and vertical paths and the minimum size of corridors and doors. After starting the analysis, the software checks the various "packages" of rules according to the limits set by the user, reporting problems and validating the parameters.

9 Test results and problems of Solibri Model Checker

From the data consistency analysis of the BIM model there is are no errors in its structure. With regard to the analysis of fire prevention, one of the main issues is the lack of elements with adequate fire resistance, such as doors, walls and windows: this discrepancy appears to be in agreement with what had been highlighted during the traditional fire analysis.

To verify the size of escape routes the rule "Escape Route Analysis" was analysed, through which it is possible to locate the escape routes, verifying that the length does not exceed the imposed limit. In addition to this, having set the size of the passages and doors, the number of planned occupants and the area assigned to each user, SMC is able to verify if the width of each frame is sufficient for evacuation, according to the crowding expected for any given space.

From this point of view, there are no problems related to the sizing of the passages and doors, so attention must be focused on the excessive length of the paths of some environments.

Performing an additional comparison with the results obtained from the calculation of the lengths through measurement made using the traditional method, (using AutoCAD 2012), we can highlight a deviation between the two values of about ten meters.

This is mainly due to the method of calculation chosen on SMC, especially in regard to the measurement along the stairs.

A further verification was carried out with the aim of reducing the escape routes, by transforming the stairwells into protected environments equipped with doors with adequate fire resistance and smoke filters so as to define a new dynamic safe place for evacuation. In this case it is not necessary to load the template again, but the classification of doors of the stairwells can be changed. In this way, the software directly modifies the extreme of the calculation of the paths.

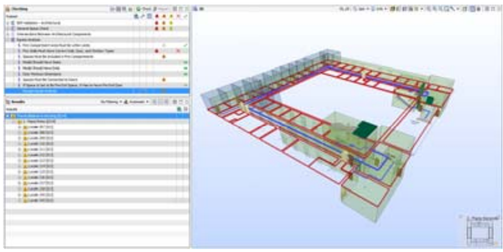

Figure 8. Screen of analysis results with Solibri Model Checker on the length of the escape routes and relevant details.

Figure 9. Graphic explanation of the traditional fire testing.

Then, the software calculates the new distance and highlights those environments which exceed the regulatory limits; graphically, the entire escape is highlighted, from the internal selected space to the outside. Comparing the two proposed solutions, we can notice a reduction of the gap between the two measurements, on AutoCAD 2012 and on SMC files: this is due to the absence of the stairs in the distance calculation.

Despite the considerable advantages of using SMC, we must take into account some gaps in the software. First of all, it is necessary to emphasize that any standards imposed, and the regulatory limits required, refer to parameters that are sometimes not the same as those set out in Italian laws: if it can, on occasion, be difficult to adapt the program requests to the user's needs, another problem is that some checks on relevant national rules could be missed.

Another important issue is the difficulty of importing the model between Autodesk Revit and SMC. This is not due to the creation of the file in IFC format and its loading, but rather to the loss of information and already-defined parameters that must be re-assigned every time. SMC assigns precise classifications to the various structural elements that must be carefully checked and modified if necessary, every time a new model is defined. If this aspect can be considered of secondary importance for an existing building, the same can hardly be said of building the new design, especially in the case of relatively complex buildings: the template cannot be directly edited. Instead, the user can only change the options or report any issues and their solutions. Each time the original project undergoes a variation, the same process of importing must be applied, carefully controlling the specific classification.

10 CONCLUSION

The case study allowed us to analyse a building belonging to the Italian historical-cultural heritage.

HBIM allowed us to perform a full survey of the building that, thanks to its three-dimensional restitution, makes it possible to consider lots of potential conservation measures, recovery, rehabilitation or functional re-use, and to perform structural, energetic and plant design analysis as well as assessments regarding the safety of the building.

However, the technology available does not allow a true representation of many features and of specific details that are beyond the seriality and prefabrication which affects new construction: for this type of modeling we can find groups of buildings that are difficult to model and we need to define *ad hoc*.

It is still essential to establish, from the earliest stages of modeling, the correct level of development to be obtained in order to streamline the resources available: according to the survey purposes it is possible to define a relative degree of accuracy of the available data in order to calibrate the quality and quantity of information for a faithful reconstruction of the buildings, and to reliably perform the analysis that we intend to carry out.

The analysis with SMC has also highlighted a number of errors that has affected the final results, if we compare to the results achieved by traditional method performed with spreadsheets and AutoCAD files. The use of automatic control, with respect to the prescriptive indications of fire prevention, would lead to considerable advantages from the economic point of view and also with regard to the management of the design for users' safety.

To solve the interoperability issue (importing data from Revit into SMC or any other model checking software), is necessary a redefinition of the input data. This interoperability problem arises from the missing semantic information in the IFC file exported from Revit. This issue is best dealt with using “Semantic

Enrichment" of the BIM model files. Further developments of this research could be done considering the semantic enrichment approach.

In conclusion, we can state that Fire Safety Engineering is the way to manage historical and artistic heritage in fire prevention. Thanks to its design flexibility, a proper use of FSE ensures a level of safety for buildings which is equivalent to that provided by means of performance standards. This approach is made easier by having a complete BIM model, so research must be directed towards the development of an appropriate level of interoperability between BIM and FSE, in order to optimize the results and to better manage the information during both the design and management phase.

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