The building information modeling for the retrofitting of existing buildings. A case study in the University of Cagliari.

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Abstract

Italy's very consistent buildings stock has become the major field for real estate investments and for the related projects and actions. The urge of working on built environment is however facing some crucial issues. The first is the lack of documentation on the construction history and on the real constructive layout of existing buildings (in terms of components, installations, plants, etc.). The second is the poor activity in surveying their current status, with reference to use (energy behaviour, real consumptions, etc.) and maintenance (conservation status, previous maintenance works, compliance with current regulations, etc.). These obstacles cause a deep inefficiency in the planning, programming and controlling of requalification and/or refunctionalisation works. Starting from these assumptions, this paper shows the findings of a research shared by the Politecnico of Milan and the Department of Civil and Environmental Engineering and Architecture of the University of Cagliari. It is aimed at testing the use of building information modeling (BIM) to structure the necessary knowledge to evaluate intervention scenarios. The research is focused on the Mandolesi Pavilion of the University of Cagliari, designed by Enrico Mandolesi. It is a highly stimulating architectural object because it incorporates values that require a conservative approach, but at the same time, like most contemporary buildings, it was designed and built for innovation and not for "long duration". The work has actually led to the realization of a BIM model of the case study. It represents the first prefiguration of an approach that develops from construction history and continues with advanced diagnostics on the statical and energy performances of the building. The model formalizes knowledge and information on a significant building, aimed at its management. It allows also the setting of intervention scenarios that can be evaluated with real-time simulations of cost, time and ROI.

Selection and peer-review under responsibility of SER4SC2018 Scientific Committee.

Keywords: Architectural heritage, construction history, space management, renovation of existing buildings, building management systems.

1. Introduction

A survey carried out on the building stock of the University of Cagliari and on its use, management and maintenance shows many critical issues due to a lack of knowledge and information about buildings. The lack of “As Built” documentation and the complex task of detecting their current status in terms of use and maintenance, causes deep difficulties in planning, scheduling and controlling appropriate interventions. The situation is worse in the case of buildings of particular historical, artistic and architectural value, so frequent within the heritage of the University of Cagliari. The need to improve the energy efficiency of existing building must deal with its values and peculiarities [1]. Pursuing both the active protection of the building heritage (particularly significant from an architectural and historical point of view) and the improvement of its energy performance, generates unavoidable conflicts [2]. From this point of view, BIM could be considered a strategic tool which represents the ideal ground for multi-disciplinary contributions: it is a tool for the coordination of cultural and architectural value analisys, advanced diagnostics methodologies, energy behavior simulation, etc. Specifically, HBIM (or BHIMM) combines the models of historic buildings, not only with geometric information [3], but also with its construction history [4], conservation status, components, installations, plants, materials, previous maintenance works, statical and energy performances. Therefore, HBIM model formalizes knowledge and information in order to achieve appropriate interventions on the building [5].

This paper shows the findings of a research shared by the Polytechnic of Milan and the Department of Civil and Environmental Engineering and Architecture of the University of Cagliari. It is aimed at creating the best conditions for an integrated and multidisciplinary strategy of requalification and/or refunctionalisation. The research, focused on the Mandolesi Pavilion of the University of Cagliari, is addressed to the implementation of building information modeling (BIM) to structure the necessary knowledge about conservation status, energy performances, maintenance procedures, compliance with current regulations, etc. The outcome is a parametric model able to formalize the cognitive process of a building (particularly significant from an architectural point of view) according to its requalification and management.

In order to have a clear and complete set of information and knowledge about the building, it is necessary to investigate the construction history, constructive techniques and technologies, previous maintenance works and actual energy performances of the building [6]. Information, gathered during the cognitive process, was digitally capitalized in order to allow a quickly and effective consultation. A detailed analysis of the state of the building was carried out to supplement the documentation. A geometric and distributive survey of the building was completed to allow immediate comparison between the current and the original configurations. The next step was to carry out surveys on the technical elements: thicknesses, materials and construction technologies. An accurate analysis about the conservation status completed the knowledge framework of the building. Finally, the performance gap and the possible interventions were assessed to:1) improve internal comfort, 2) ensure code re-alignment, 3) ensure energy efficiency in respect of the architectural values of the building [7]. The last step of the work was the development of the BIM model, which allowed to capitalize and organize the collected information: each virtual element was "informed" with all the parameters and features of the real element of the building.

2. The Mandolesi pavilion: prefabrication of lightweight components

"It is a work where Mandolesi's choice of the functional organization, the use of metadesign instruments (functional modules, preferential frameworks and so on), the resorting to particular constructive elements, the adoption of on-site prefabrication techniques, can be better understood if placed within his whole work as designer and scholar". With those words Gianfranco Carrara introduced the building, at that time hosting the Institute of Mining Engineering and Applied Chemistry of the University of Cagliari, on a journal in 1972 [8]. In the same period Mandolesi founded the Institute of Architecture at the same University, with the aim of driving the research towards the modernization of the relationship between architectural design and construction.

The shape of the building is generated by the extrusion of transversal section that expresses the organization of the complex: from the pilotis floor rise two cantilever stories the basement exploits the different height of the near street and hosts the laboratories and a lecture hall. The upper stories are divided in three longitudinal zones separated by two aisles. The external ones hosts offices for researchers, the inner is divided in laboratories and services, ventilated and enlightened by open shafts. The flat roof recalls the Le Corbusier's garden terraces.

Fig. 1. The Mandolesi pavilion (Photo by Bruno Meloni)

The use of concrete for the in-site precast of bearing elements and envelope panels is coherent from the technological and constructive point of view. The choice of the fair-faced finishing is coherent with Ridolfi's lesson on "the honesty of materials" and before that, with the experimentation on megastructures from Kenzo Tange. Mandolesi's brutalism is able to transmit the sense of an innovative research, among the trivial and old-fashioned surrounding buildings.

The internal distribution asset of the building space is based on the realization of a strong integration between the areas of research and teaching. The article by M. Rebecchini in the Journal "*L'industria italiana del cemento*" [9] reports the following concept: "this work identifies itself with a proposal of behavior, with the message of a way of teaching and learning transmitted through the exact evaluation of the expressive capacity of the materials and the perfect technical solution of each element" without rejecting the use of the most advanced prefabrication. The wide corridors and the glazed doors of study and teaching spaces ensure smooth relationships and constant visual contact with experimental laboratories that are centered in the core.

Fig. 2. View of the interior spaces of the Mandolesi pavilion

The terrace, as well as the pilotis floor, is reserved for the common spaces, the meeting and relax. At this floor, the spaces for outdoor meetings and small study and research rooms have been created. The basement floor has a distribution disconnected from the compositional rules of the facade. It only responds to the requirements imposed by the use of machinery.

While the construction process of concrete facade panels and structural elements reveals a work of integration between prefabrication and artisanal processes, in the monobloc fixtures and in cross-sectional interior panels, prefabrication formulas have been applied without mediation.

The facade module, projected on the floor, divides the net distance between the pillars in nine parts and traces the position of the transversal internal partitions. In the original design, such partitions were provided in masonry (at the two joints of the building) and with matt or glazed panels in all the other cases.

During the work, at the request of the Institutes' Directors, many panels were replaced with masonry partitions. The partition panels represent the clearest result of a standardization process that finds its reasons both in technological and economic aspects as well as in cultural and sociological aspects. These partition panels, with an aluminum frame, are inspired by the Nordic tradition of construction. They were factory-made and then assembled into the completed building. The panels have a total thickness of 70mm and inside the aluminum frame, the electrical wirings were installed. The aluminum frame divides the panels into modules which, in the original design, were supposed to be realized by semi-double glazed or honeycomb wood covered with a plastic laminate or with mahogany wood with polyester finish (this option was then excluded at the request of the Institute’s Directors). The need for perceptional continuity within the building also prompted the author to integrate the partition panels with the furniture elements and internal doors. While outside the indisputable protagonist is the concrete, inside no material seems to overpower the other. The glasses, the coatings of the partition panels, masonry partitions, concrete ceilings, the tiles of the floors, the slabs of plywood for the countertop contribute to the characterization of the internal spaces and paths.

For the execution of these works, the Ora-Acciaio company in Rome was selected. The work started on January 8, 1968 and ended on October 11 of the same year. The work was carried out on the basis of the executive drawings, the details of the contractor and the suggestions and requests of the users. An elaboration process that attests the author's attention to collaboration approach between researchers, designers and manufacturers. This approach derives from the experiences of Wachsmann and Fuller.

3. The BIM methodology for building heritage management

BIM method involves the elaboration of a parametric model that can gather the information that should be shared between all the subjects involved in building management. Therefore, after the building's recognitive analysis was completed, the selection of the information to be capitalized was carried out. The BIM model, in fact, does not represent the universal container for every type of information, but must be conceived within a specific and focused programme. In this phase of the work, already outlined in the contribution [10], the necessary information for each technical element were identified.

The production of suitable schedules has allowed to specify and collect all the necessary data to "inform" each virtual component of the model: geometric and material features, level of degradation, residual performance and interventions in accordance with the particular architectural and historical values. After selecting and collecting building information, the work focused on defining the most appropriate detail level of the model. This phase, defined as pre-modeling, is considered to be fundamental as it specifically determines the degree of graphic and information detail (LOD and LOI) needed to achieve the set goals. Finally, a set of parameters required to “inform” the components of the model were selected.

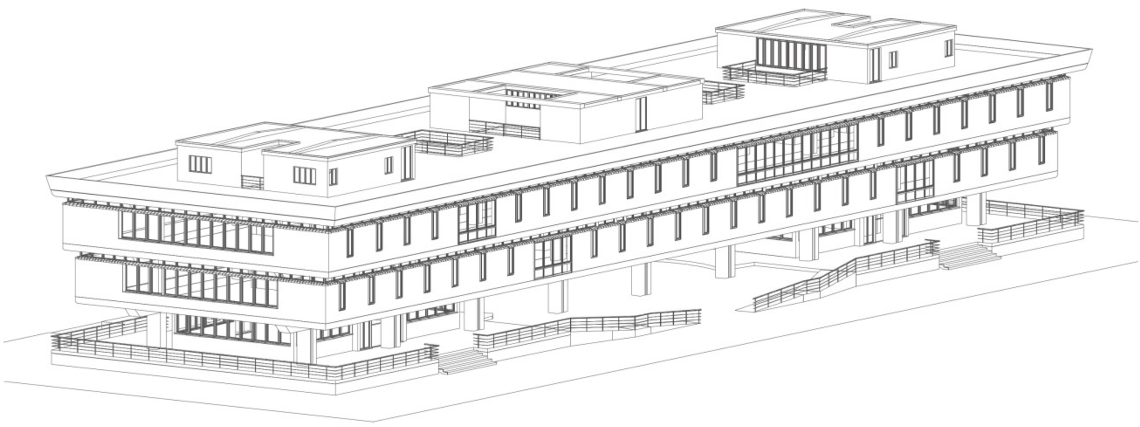


Fig. 3. BIM model of the Mandolesi pavilion

The complexity of the Mandolesi Pavilion's parametric model is related to the irregularity of particular elements of the building, such as pillars, beams and the internal stairs. The need to keep track of this irregularity has resulted in the almost exclusive use of the "in-place families" of Revit software. The “in-place families” have the peculiarity of being created in the current project, they have the disadvantage of not being able to use them in other projects, and their massive also generates a very heavy model file. Despite the recognized disadvantages, their use has made it possible to obtain the best result for the management approach of the Mandalesi Pavilion: the faithful representation of the various components of the building at the level of complexity and geometric peculiarity. Avoiding excessive simplifications has made it possible to preserve precious details for the planning of restoration and re-functionalization work.

The particular shapes of the components of the building within the modelling frame were reproduced, by using commands such as extrude, join and revolve.

The created model allows us to record and manage the information relating to the architectural and historical features of the building, its current status, materials, techniques and constructive technologies used, the results of diagnostic surveys, the conditions of degradation in terms of type and severity, interventions and treatments performed, restrictions relating to its particular architectural value and degrees of freedom for new interventions. An important feature of the model is that it can be updated and integrated at any time in the life of the building. This aspect solves a further critical issue, namely the difficulty of ensuring the “information requirements” for the management of the building after the restoration works. The model, infact, creates the structure which organises all the data and information that are produced during any new intervention work and that is functional to the innovative management of the building.

4. The BIM model between conservation and new usage patterns

The parametric model is an essential tool capable of integrating and coordinating different but complementary skills and contributions (structural engineers, energy efficiency experts, plant engineers, restorer architects, technical physicists, etc.). The structuring and management of a wide range of digital data and information about the status of the building and its history creates the best conditions for conducting a “multicriteria” analysis that would allow the design and evaluation of different scenarios and intervention strategies, identifying the combination that maximizes the quality of the results.

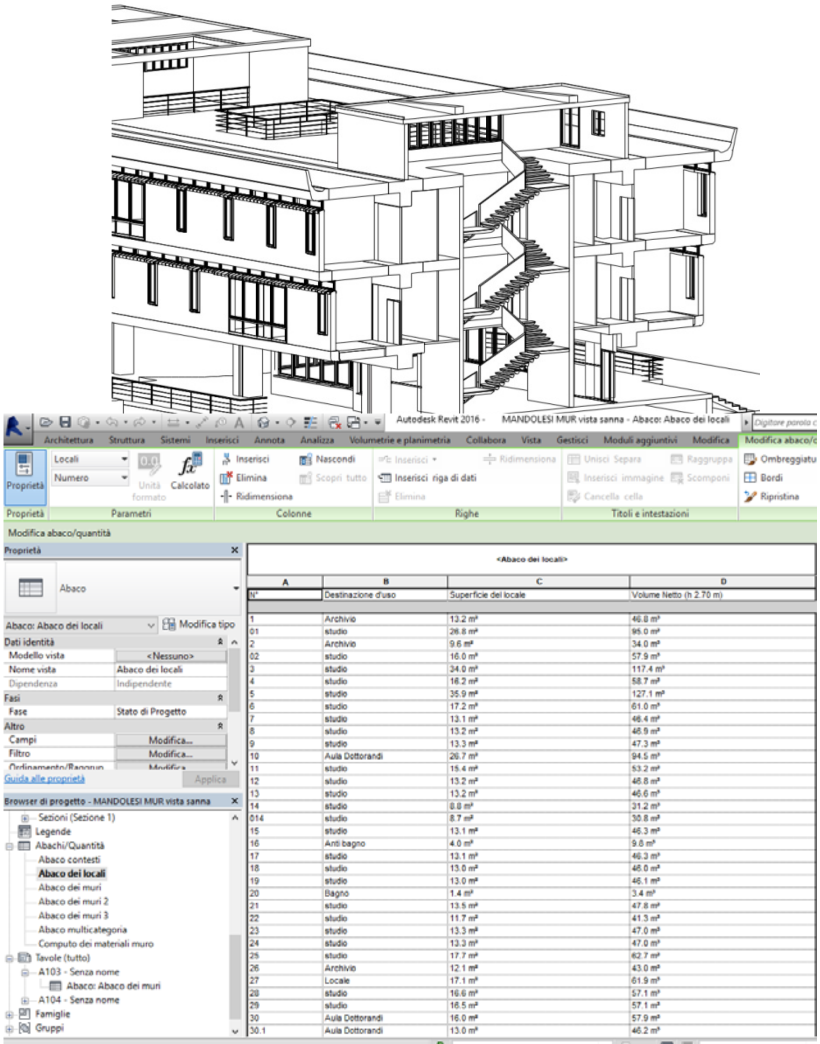
Therefore, the BIM model performes an important supporting action during the next phases of simulation and evaluation in therms of the best intervention scenarios. These intervention scenarios, which are aimed at a meeting new users requirements and at complying with current regulations, must respect the architectural-historical peculiarities of the case study. In this regard it was intended to highlight that the preservation of historical-artistic value of the building in question is closely linked to the need of a large volume of information in order to provide an appropriate information base for planning conservative restoration or maintenance interventions.

The buildings are built to accommodate different functions. If on the one hand the envelope performances, the efficiency of the installations are very important to meet the intended function, on the other hand, it is crucial to see how the building internal spaces are still able to support the activities taking place inside. This aspect is more evident in old buildings which require a complete redefinition in terms of plants, structures, energy performances but also distributive issues. The radical change in the use patterns of the building during its life cycle leads to the need to analyze current distribution requirements. Building internal spaces have to be revised in order to meet the new needs of the users. Often the inadequacy of existing buildings is due to the fact that old functional patterns do not respect current standards. This analysis becomes more complicated when the target of analysis are buildings of significant historical-iconic value, as in the case of the Mandolesi Pavilion. The need to adapt the internal spaces distribution to the new building use patterns contrasts strongly with the need to preserve the design philosophy of the original functional scheme envisaged by Enrico Mandolesi. The partition elements (panels and masonry) that define the interior distribution of the building represent a characterizing element of the Mandolesi pavilion project. The availability of a rich database which is configured as the catalog of these components with all the information about them, enables: 1) to keep track of the history of the building, 2) to make simulations which allow to predict more alternative solutions regarding a new distribution scheme of the internal space of the building and then to make a shared choice.

1	Famiglia e tipo	Descrizione	Larghezza	Lunghezza	Elaborati di progetto	Immagine	Area
287	Muro di base: T2	Muratura faccia a vista (forato 12x12x25cm)	0.12	5.83		20171019_094932.jpg	20.53 m²
288	Muro di base: T2	Muratura faccia a vista (forato 12x12x25cm)	0.12	1.33		20171019_094932.jpg	1.83 m²
289	Muro di base: T2	Muratura faccia a vista (forato 12x12x25cm)	0.12	1.42		20171019_094932.jpg	4.24 m²
290	Muro di base: T2	Muratura faccia a vista (forato 12x12x25cm)	0.12	1.33		20171019_094932.jpg	3.93 m²
291	Muro di base: T2	Muratura faccia a vista (forato 12x12x25cm)	0.12	4.72		20171019_094932.jpg	15.96 m²
292	Muro di base: T2	Muratura faccia a vista (forato 12x12x25cm)	0.12	4.72		20171019_094932.jpg	15.96 m²
293	Muro di base: T2	Muratura faccia a vista (forato 12x12x25cm)	0.12	4.78		20171019_094932.jpg	15.96 m²
294	Muro di base: T2	Muratura faccia a vista (forato 12x12x25cm)	0.12	4.72		20171019_094932.jpg	15.96 m²
295	Muro di base: T2	Muratura faccia a vista (forato 12x12x25cm)	0.12	4.78		20171019_094932.jpg	15.96 m²
296	Muro di base: T2	Muratura faccia a vista (forato 12x12x25cm)	0.12	5.96		20171019_094932.jpg	19.70 m²
297	Muro di base: T2	Muratura faccia a vista (forato 12x12x25cm)	0.12	1.86		20171019_094932.jpg	4.11 m²
298	Muro di base: T2	Muratura faccia a vista (forato 12x12x25cm)	0.12	2.23		20171019_094932.jpg	7.05 m²
299	Muro di base: T2	Muratura faccia a vista (forato 12x12x25cm)	0.12	2.27		20171019_094932.jpg	5.32 m²
300	Muro di base: T2-T3C	Muratura faccia a vista (forato 12x12x25cm)/parete mobile mogano con armadio H=210cm	0.19	4.02	20172021_084972.jpg	20171019_110113.jpg	13.30 m²
301	Muro di base: T3 A	Parete mobile in mogano e vetro e armadio H=120 cm	0.07	4.08	20172022_084972.jpg	20171019_100417.jpg	13.30 m²
302	Muro di base: T3 A	Parete mobile in mogano e vetro e armadio H=120 cm	0.07	4.08	20172022_084972.jpg	20171019_100417.jpg	13.30 m²
303	Muro di base: T3 A	Parete mobile in mogano e vetro e armadio H=120 cm	0.07	4.08	20172022_084972.jpg	20171019_100417.jpg	13.30 m²
304	Muro di base: T3 A	Parete mobile in mogano e vetro e armadio H=120 cm	0.07	5.96	20172022_084972.jpg	20171019_100417.jpg	19.70 m²
305	Muro di base: T3 A F	Parete mobile in mogano e vetro e armadio H=120 cm/parete mobile mogano con vetro	0.07	4.78	20172023_084972.jpg	20171019_100417.jpg	15.96 m²
306	Muro di base: T3 B	Parete mobile in mogano con mobile H=120cm	0.07	4.08	20172024_084972.jpg	20171019_095538.jpg	13.30 m²
307	Muro di base: T3 B	Parete mobile in mogano con mobile H=120cm	0.07	4.08	20172024_084972.jpg	20171019_095538.jpg	13.30 m²
308	Muro di base: T3 B	Parete mobile in mogano con mobile H=120cm	0.07	4.08	20172024_084972.jpg	20171019_095538.jpg	13.30 m²
309	Muro di base: T3 B	Parete mobile in mogano con mobile H=120cm	0.07	4.78	20172024_084972.jpg	20171019_095538.jpg	15.96 m²
310	Muro di base: T3 B - D	Paete mobile in mogano con armadio H=120cm/parete mobile "piena"	0.07	4.08	20172025_084972.jpg		13.30 m²
311	Muro di base: T3 C	Parete mobile in mogano con armadi H=210cm	0.07	3.14	20172026_084972.jpg	20171019_110113.jpg (2)	6.52 m²
312	Muro di base: T3 C	Parete mobile in mogano con armadi H=210cm	0.07	4.08	20172026_084972.jpg	20171019_110113.jpg (2)	13.30 m²
313	Muro di base: T3 C	Parete mobile in mogano con armadi H=210cm	0.07	4.08	20172026_084972.jpg	20171019_110113.jpg (2)	13.71 m²
314	Muro di base: T3 C	Parete mobile in mogano con armadi H=210cm	0.07	4.08	20172026_084972.jpg	20171019_110113.jpg (2)	13.30 m²
315	Muro di base: T3 C	Parete mobile in mogano con armadi H=210cm	0.07	4.02	20172026_084972.jpg	20171019_110113.jpg (2)	13.30 m²

Fig. 4. Information and data sets

Therefore, the BIM method could be a valid space management tool which ensures accurate visualization and accurate management of internal spaces of the building and objects within it.



<Abaco dei locali>

A	B	C	D
N°	Destinazione d'uso	Superficie del locale	Volume Netto (h 2.70 m)
1	Archivio	13.2 m^2	46.8 m^3
01	studio	26.8 m^2	95.0 m^3
2	Archivio	9.6 m^2	34.0 m^3
02	studio	16.0 m^2	57.9 m^3
3	studio	34.0 m^2	117.4 m^3
4	studio	16.2 m^2	58.7 m^3
5	studio	35.9 m^2	127.1 m^3
6	studio	17.2 m^2	61.0 m^3
7	studio	13.1 m^2	46.4 m^3
8	studio	13.2 m^2	46.9 m^3
9	studio	13.3 m^2	47.3 m^3
10	Aula Dottorandi	26.7 m^2	94.5 m^3
11	studio	15.4 m^2	53.2 m^3
12	studio	13.2 m^2	46.8 m^3
13	studio	13.2 m^2	46.6 m^3
14	studio	8.8 m^2	31.2 m^3
014	studio	8.7 m^2	30.8 m^3
15	studio	13.1 m^2	46.3 m^3
16	Anti bagno	4.0 m^2	9.8 m^3
17	studio	13.1 m^2	46.3 m^3
18	studio	13.0 m^2	46.0 m^3
19	studio	13.0 m^2	46.1 m^3
20	Bagno	1.4 m^2	3.4 m^3
21	studio	13.5 m^2	47.8 m^3
22	studio	11.7 m^2	41.3 m^3
23	studio	13.3 m^2	47.0 m^3
24	studio	13.3 m^2	47.0 m^3
25	studio	17.7 m^2	62.7 m^3
26	Archivio	12.1 m^2	43.0 m^3
27	Locale	17.1 m^2	61.9 m^3
28	studio	16.6 m^2	57.1 m^3
29	studio	16.5 m^2	57.1 m^3
30	Aula Dottorandi	16.0 m^2	57.9 m^3
30.1	Aula Dottorandi	13.0 m^2	46.2 m^3

Fig. 5. Internal spaces schedule

BIM applications can then be extended to other features such as spatial rule control in managing change scenarios (new usage patterns). Through the continuous model analysis with code-checking systems it will be possible to ensure that the refunctionalisation works complies with the requirements specified by users and by rules and regulations.

In addition, the accurate parametric representation of the building could support during the choice of emergency and security measures. Interactive simulations can be used to assess people's flows, exit corridors, high-risk areas of crowding and also to establish security camera placement to provide an effective surveillance.

5. Conclusions

The boundaries drawn by the traditional disciplines are increasingly called to leave enough space for mutual contamination. Especially, this is crucial in fields of high complexity such as the management of the building heritage of high historical and architectural value, where it is essential to integrate techniques and values that arise in very different disciplines. In this sense, BIM is the ideal ground for multi-disciplinary contributions. Building Information Modeling/Management methodology is considered a strategic tool which could coordinate and integrate: the studies of cultural and architectural values of the building, static features, energy efficiency issues and usage patterns of the internal space of the building.

This work represents the first and, as yet, partial prefiguration of an approach which develops from construction history, a powerful tool for highlighting the values and critical aspects of the building, and continues with advanced diagnostics on the dimensional survey, structures and energy performance of the building. Therefore the use of Building Information Modelling/Management (BIM) was experimented for structuring the cognitive process and for assessing enhancement and re-functionalisation scenarios. The Mandolesi Pavilion of the University of Cagliari is a highly stimulating architectural object for us. In fact, as an “author building”, it incorporates values that require a conservative recovery approach, but at the same time, like most contemporary buildings, it was designed and built for innovation and not for “long duration”.

Through the application of Building Information Modeling, the integration of different (and sometimes opposed) needs, skills, cultural and specialist points of view in defining and evaluating different scenarios and intervention strategies was experimented, trying to identifying the best combination that maximizes comprehensively the quality of the results.

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