Collaborative BIM-AR Workflow for Maintenance of Built Heritage

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Abstract

The research proposes a BIM-AR workflow to ensure the monitoring of the built heritage. Indeed, the application of AR might be an extension of the BIM since it allows during the on-site surveys' phases to add and update punctual information within the BIM model overcoming the traditional survey methods based on cards. Consequently, the information models can act as collaborative tools at the service of public autorithies and stakeholders, thus supporting an efficient building management, also from a preventive perspective. The research is a development based on the results of the Fondamenti di modellazione BIM per il settore delle costruzioni [1] academic course of the master's degree course in Ingegneria Edile-Architettura [2] of the University of Padua. Starting from the students' BIM models, the workflow exposes the integrability of the AR during the on-site survey campaigns of a case study to verify the geometric accuracy and the structural problematics of the BIM models overlapped to the real buildings by recording the information directly on them.

Keywords
BIM, AR, maintenance, facility management, education.

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The BIM methodology and the Importance of Proper Sharing Practices

Nowadays the BIM (Building Information Modelling) is an essential aspect in both engineering and architectural practice. Although a simplistic conception of the BIM approach still persists, the stringent regulations introduced in the normative corpus, both national and international, are leading to an ever deeper understanding of the concept. The result consists in a more in-depth informatization of the models created which tend to become databases not only of spatial-dimensional geometric aspects, but also of all the aspects related to the management of the life cycle of the building, whether they are historical or newly manufacts [Volk et al. 2014, pp. 109-127] .

Nevertheless, the deep understanding of the usefulness of BIM is also related to necessary procedures in order to take a full advantage of its use in the most correct and manageable way. Very often numerous personalities are involved within the design team of a project, each one with specific knowledge and skills. This aspect, if not related to proper practices and understanding of the proper manage of the different tools, can cause problems in terms of timing and information sharing within the design process by the various personalities involved [Bosch et al. 2015, pp. 331-343].

Related to the production of documentation by the different parts involved in the project teams, fundamental is also the aspect assumed by the sharing of the models and documentation through proper files formats: this aspect has a key role related to the information exchange inside a more wider collaborative process known with the name of openBIM [Jiang et al. 2019; Jo, Choi 2021]. It is an approach, whether through shared platforms or individual exchange, which guarantees the efficiency of the BIM process, endorsing to the requirements imposed by legislation in favour of a more virtuous one in terms of timing and accuracy of information, especially in terms of public works. Such a practice, if coherently marked through the workflow shared by the different actors involved, as well as by the authorities proposing the works, may lead, to a deep change in the concept of information cataloguing in favour of systems for integrated digital management of artefacts (BMS).

UNIPD BIM Educational Aim

It's precisely the understanding of constant updates within the BIM concept and the teaching of this profound conception that is one of the aims which the University of Padua has been proposing in recent years within the master's degree course of Ingegneria-Edile Architettura, specifically in the Fondamenti di modellazione BIM per il settore delle costruzioni course.

The need to teach the correct practices of BIM, from geometric-spatial modelling to informatization and sharing practices, becomes a precious baggage of knowledge and professional skills for students for their future careers to be able to face efficiently the increasingly demands of the labour market in the architecture and engineering sector, as well as of public administration. In fact, it has been seen how many students, through feedback with former of them, after completing their studies, have found employment in the sector of studies' specialization and particularly within professional firms and companies that require the mastery of BIM as design tool tout court of a broader integrated process.

During the academic year 2020/2021, the Fondamenti di modellazione BIM per il settore delle costruzioni class [3], has offered to the students a knowledge strongly oriented to the aforementioned BIM perspective, paying particular attention to classification and sharing information topics and practices, often underestimated and sacrificed in favour of the only geometric-spatial modelling, in continuity with the common simplistic perspective of BIM practice.

To offer students the most complete and structured possible knowledge, an operational workflow has been equipped to both organize the phases of the course, but also to propose a practice adoptable by the University of Padua for the management of the built heritage. With this purpose, the course proposed real case studies relating to the UNIPD building heritage, as buildings to be modelled and informatized, thus generating operationally valid digital twins that can be used in various phases of the management of the buildings over the years.

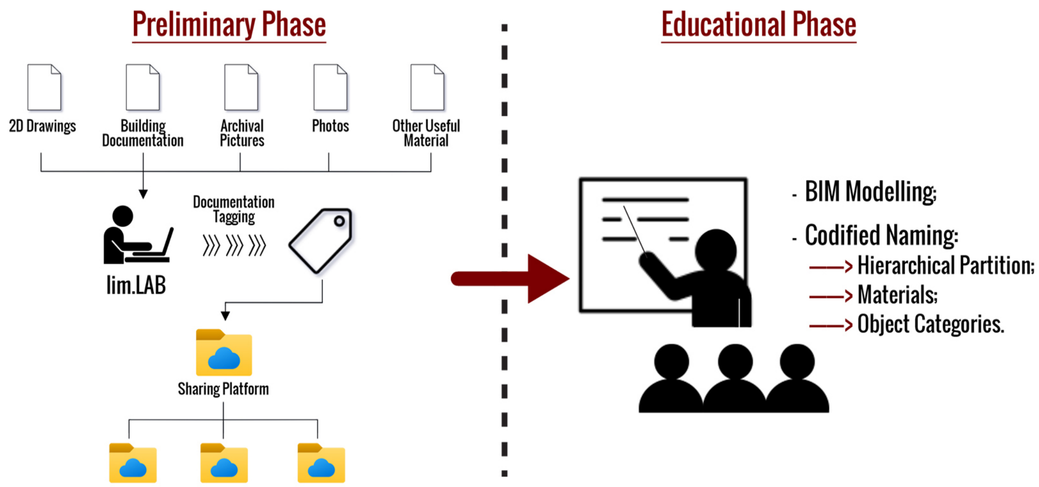

Fig. 1. Operative phases of the first part of the researc.

The academic program was organized in two phases (Fig. 1). The first one had as its purpose the informative systematization of the material according to the documents' typologies made available by the University of Padua and other institutions, according to an alphanumeric code based on the use of the UNICLASS 2015 in order to organize the material through different levels of reading. The cataloguing of the input files obtained therefore provided for the assignment of tags for each individual file in line with the notions contained in reference to the Structural Brakedown System, Role and Project Management for each building. This informative structure then was made available to students for the developments of their projects. The vastness of the documents, which ranges from historical archive files to *in-situ* photographs, from dated and recent project drawings to construction estimates, has thus found a first indexing suitable for the exploitation of easier targeted research paths. In support, a naming was implemented for the same files, which in accordance with the building project, the specific part of the same, the area, the project phase, the specific discipline of the document and the type of document, assigns the name to the file using sequential alphanumeric characters.
The second phase, viewed the teaching of the correct consolidated modelling practices through BIM software for the models' generation, but with it, also the teaching of further best practices aimed at sharing the models and documents generated between students, as well as with the reviewing teachers.
The students, organized into groups, were then assigned the specific case studies with the related input materials already systematized, and the creation of the BIM model was requested, paying attention to the implementation of further information based on precise nomenclatures studied to informatize specific aspects such as spatial hierarchy, materials and types of objects used for modelling. The proposed case studies are existing buildings, some belonging to the patrimony of the University of Padua, but also others of public interest such as provincial school buildings and others of historical, artistic and religious value. The choice of this typological variety has offered students the opportunity to explore different aspects of the digitization BIM process which, although unique from a methodological point of view, requires specific attention strictly deriving from the particular type of building under consideration.

AR-BIM Integration

The outcome of this digitization process is represented by the students' production of BIM models of existing aforementioned buildings which are very heterogeneous in terms of function and levels of architectural value.
The three-dimensional models were used for testing a workflow that involves the integration of Augmented Reality within the BIM methodology aimed at facilitating the management of buildings during their life cycle.

With reference to the first definitions and to the schema published in 1994 by Milgram and Kishino [Milgram, Kishino 1994], AR is defined as a system capable of enriching physical reality by adding virtual content, using a technological tool as an intermediary [Russo 2021, p. 4]. This, in a wider view, is part of the general domain of Mixed Reality (MR), as it is properly inserted at the intersection between the real and the virtual worlds. Thanks to this specific characteristic, the AR is becoming extremely widespread in many fields and among them, the AEC sector is also following this trend.
In recent years, the purposes and use cases related to the implementation of AR in the construction industry have found progressive applications in academic literature and the professional field [Alizadehsalehi et al. 2020]. In reference of the proposal in [Russo 2021, pp. 24-28], these use cases can be divided into three macro-research areas:

• AR for the enhancement of the built;
• AR for the design and construction process;
• AR for professional training and education;

The first category, strictly related to the Cultural Heritage sector, involves all those researches aimed at improving the buildings' knowledge, fruition, and maintenance. In these cases, AR plays a fundamental informative role in making the physical space's impact more effective and engaging to the user, be it a tourist, a designer or a manager. [Russo 2021, pp. 25-26]
The second application area includes all the trials in which AR supports design and construction, both on architectural and urban scale [Katahira, Imamura 2016]. In this way, similarly to VR, AR is part of highly collaborative design approaches, capable of optimizing the design and decisional phase through innovative visualizations of multidisciplinary analyses [Fukuda et al. 2015].
As regards the construction phases, there are many applications proposed to supervise its evolution during the different stages; by exploiting the possibility of overlaying the virtual project on the reality, the researches show extremely positive results in terms of safety [Li et al. 2017], logistics management, prevention and reduction of inaccuracies with consequent reduction of both time and costs [Park et al. 2013].
Finally, the third area involves all the cases in which Augmented Reality is used to guide a learning process [Russo 2021, p. 27]. In AEC sector there are more and more applications in which, through the virtual superimposition of information, AR supports workers in carrying out assembly activities or in implementing directives on the mitigation and safety of workplace's risk [Cuperschmid et al. 2016].
However, despite a richness of contributions, the literature seems to deal in an uneven way with the extensiveness of AR application fields in the AECOM sector, resulting limited with respect to possibilities that might be offered by integrating it with Building Information Modeling and Facility Management approaches.
Based on the literature of recent years, there is a prevalence of research focused on the usage of AR systems during the first design and construction stages, giving limited interest to the subsequent life cycle management of the buildings [Alizadehsalehi et al. 2020; Wang et al. 2013, p. 6]. This consideration points out a partial exploitation of the technological integrability potential and the results, in a broader perspective not only of BIM, but also of the entire construction sector, appear reduced if compared to the effective usefulness that XR could offer.
A wider view in respect of the AR applications would therefore be desirable because if correctly related with BIM, a virtuous support and development process of data sharing would be introduced. This integrated methodology aimed at optimizing the informative organization during the several phases of the construction process, as well as the management of the asset by the manager, avoiding the risk of information overloads and inconsistencies [Chu et al. 2018].
This gap represents a strong incentive for the potential development of hybrid solutions with the common purpose of improving the building process, from design, to construction, to the management of historic and newly built assets.

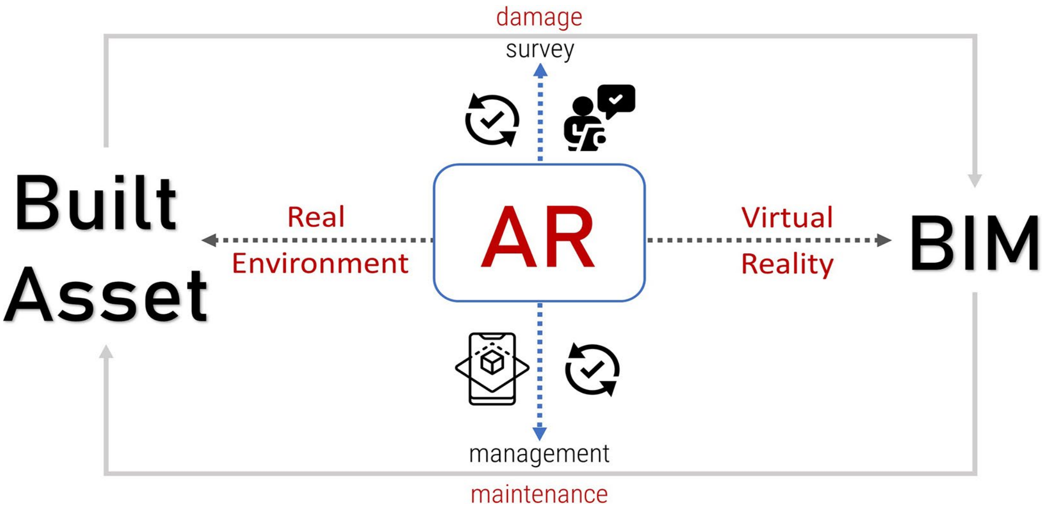

Fig. 2. Milgram and Kishino's schema reinterpretation, adapted to BIM-AR integration

Challenged by these potentials, the research offers the chance to optimize the monitoring activities and consequent management of buildings, allowing the information contained within the BIM model to be updated directly in situ.
In this process, Augmented Reality (Fig. 2) acts as a medium between the virtual and physical environment, becoming a support for interoperability, conveying the informative apparatus from the design to the construction and management phase [Alizadehsalehi et al. 2020].

Aims and Requirements for Suitable AR Software

Starting from this awareness and the purpose to verify the potential of the BIM-AR on a real case study, an operative workflow was aimed at simplifying the information updating activity during the inspection phase and at facilitating the following management phase of existing buildings.
The operative phase was preceded by a preliminary review of the characteristics of the AR systems available on the market in order to satisfying two main needs: information accuracy and interoperability through a collaborative environment.
The first requirement derives from the inherent nature of the BIM collaborative process of consistent data conservation. For this reason, a solution was therefore sought that would preserve the integrity of both the geometric and informative structure, limiting data loss to a minimum during the exchange and export process. This need acquires a key value as the BIM models represent structured coherent databases resulting from careful modelling set on a virtuous organization of the information inputs. For this reason, the conservation of this 'strong' data assumes a key role in the proposed pipeline.
The second constrain is the collaborative approach linked to a central synchronization system of the data flow with the model. Inside a large range of solutions, were considered only the ones that can guarantee a multi-user sharing of the BIM model on several types of devices, ensuring in a single digital environment a complete exchange and communication of information.
In sight of these needs and reasons, the most appropriate software was considered Unity Reflect, a package proposed by developers by the homonymous graphic engine, including plugins and a real-time BIM viewer (Unity Reflect Review).

Proposed Workflow

The workflow (Fig. 3) experimented is developed by considering as a case study the federated BIM models produced using Autodesk Revit software by the students who have been assigned the Mechanical Engineering building complex of the University of Padua.
The first phase of the process involved an "export", through the dedicated plugin, of the complete BIM model within a new Unity Reflect project, shared with the entire research

group. It is essential to point out that this "export" phase takes the form of a multi-platform link in real time between the model in the Unity Reflect project and the starting BIM file. Clarifying this aspect underlines the integrity information key necessity because the link and synchronization process in local and cloud mode of the two models guarantees the reduction of data loss and allows constant updating of the same.
Following the connection process, the model is visualized through a simple app, which can be installed on fixed and mobile devices. This tool offers the main features of a BIM viewer, but also allows navigation modes in augmented and virtual reality, also supporting the use of viewers or other external devices for immersive usage. However, a fundamental aspect of the research is the opportunity of sharing the project between different designers and stakeholders, who can simultaneously access and check the model in real time, from any type of device.
The research then explored, verified and evaluated the applicability of the main available features offered by the Unity Reflect package to support Augmented Reality for the specific case study and which differ according to the scale of representation and the tracking system of the elements in the physical reality.
These are:

- View Match, able to load the model in 1:1 scale, aligning it based on the extraction of features detected by the internal device camera;
- Corner Match, capable to show the model in 1:1 scale starting from the detection of an edge of the building and a horizontal plane near it;
- Tabletop, able to display the model on a variable scale by anchoring it to a flat surface;
- AR Marker, capable of displaying the model in variable scale after scanning a QR code used as a physical marker [4].

After verifying the different approaches related to the objective aimed at defining the research purpose, it was observed that the first two modes are more functional. In particular, the "Corner Match Tracking" approach was opted as it is able to guarantee greater stability and precision in the identification and connection between real and virtual elements through an efficient markerless tracking system in the operative phase.
Once the two realities were connected, by superimposing the BIM model on the physical building during a quick on-site campaign, it was possible to approach the different monitoring operations. We then proceeded to evaluate the accuracy and geometric inconsistencies of the virtual model, as well as the reliability and progress of the students' information modelling and implementation processes.
From the results observed during the survey campaign, the collaborative annotation process was then verified and systematized: specifically, synchronized reporting tests were carried out with respect to some erroneously modelled objects, indicating the conflicts, but also typical problems that can be traced during the verification of the conditions of the real buildings (expulsion of iron covers, detachments, presence of vegetation, etc.).

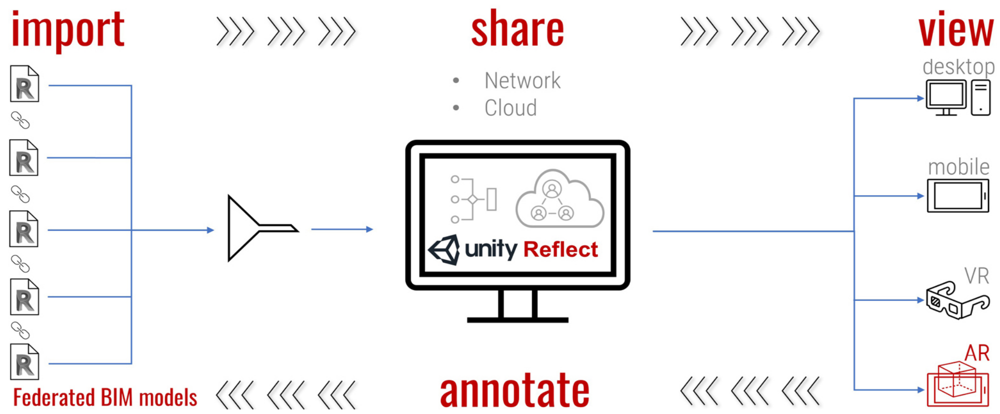

Fig. 3. Operative workflow schema

These annotations, made directly *in situ*, are synchronized in real-time and in-cloud in the BIM model on the sharing platform, updating a specific field that becomes instrumental not only to the expert who is operationally surveying the building, but also of all the professional figures involved in both the technical modelling process and in the management of the asset.

Conclusion and Future Developments

From the results of the research it is evident that BIM-AR integration can become an excellent practice supporting not only the digitalization process of new and built assets, but also for the consequent activities related to the management and maintenance phase. Furthermore, the development of the research highlights the applicability, albeit in the specific case related to a building of relative recent construction, also to buildings of historical and artistic interest. From a hBIM perspective, in fact, where the building is often bound by regulatory protection requirements, the integrability of the AR, through its non-invasiveness, enables more precautionary investigation campaigns, also in relation to the different stages of development of the building investigated. Such an investigation, related to the information update, leads to complete models from a spatial, configurative and informative point of view, giving the possibility to redact documentary and digital apparatuses that are extremely useful for understanding the historical-artistic importance of the buildings.
Thanks to the importance of managing these aspects within the entire AEC sector, the application of the proposed workflow can become an added value to be introduced to the professional knowledge base within university teaching by increasing the level of competence of students. with a view to greater competitiveness in entering the world of work.
An operational proposal for this purpose will be the development of sessions and practical experiences in which students are encouraged to exploit the proposed BIM-AR integration to approach the creation of even more structured and complex BIM models, thus leading to a virtuous process of development of didactics oriented towards advanced digitalization through emerging technologies.

Fig. 4. Screenshots taken during the experimentation of the proposed workflow.

Notes

[1] Academic course of Building Design.

[2] Master's degree course in Building-Engineering and Architecture.

[3] The course was coordinated by Prof. A. Giordano and assisted by the LIM.lab (Laboratorio di Modellazione Informatizzata) research group of the DICEA (Dipartimento di Ingegneria Civile, Edile ed Ambientale).

[4] This tracking method was introduced after our testing phase, therefore it has not been evaluated in this research.

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