INTEGRATING BUILDING INFORMATION MODELING AND AUGMENTED REALITY TO IMPROVE INVESTIGATION OF HISTORICAL BUILDINGS

Francesco Chionna, Francesco Argese,
Vito Palmieri, Italo Spada, Lucio Colizzi*
Centro di progettazione, design e tecnologie dei materiali (CETMA), Brindisi, Italy

Keywords: information modeling, augmented reality, software engineering, computer vision

1. Introduction

Nowadays conservation of historical buildings requires structural engineering studies during the evaluation and preservation process [1].This process, moreover, needs a preliminary investigation of the structural condition, involving the use of non-invasive and non-destructive technologies, such as thermography, stratigraphy and tomography. During the first phase of the conservation process (known as the Knowledge phase), a structural engineer acquires data on the site and then analyzes them in his office without having a contextualized view of the entire problem.
In recent years, new technologies have emerged, allowing the development of new tools, which help to simplify access to information about the historical building. In particular, developments in the field of Building Information Modeling (BIM) and Augmented Reality (AR), have opened new perspectives that have improved the typical investigation process [2]: BIM offers a digital representation of the physical and functional characteristics of a facility [3], while AR offers tools to view a physical, real-world environment *augmented* by computer-generated information [4].
In this scenario, this paper presents an experimental study which describes the process developed to build a tool aimed at improving the investigation of historical buildings. The study includes:

1. BIM information based on IFC (Industry Foundation Classes) file format;
2. AR visualization of BIM information using tablet and 3D glasses, contextualized to the scenario that the user is watching.

Most of the work in this experimental research addressed:

- retrieving and developing BIM information related to the historical building by integrating data from non-invasive tools;
- evaluating AR as a visualization tool to display BIM information, contextualized to the building scenario the user is examining.

The results were tested on the case study “Monastero Fortezza di Santo Spirito”, a fortified monastery, located in Ocre in the province of L’Aquila, Italy.

* Corresponding author: lucio.colizzi@cetma.it

2. Related Studies

Other works have been proposed on the use of BIM and AR to improve investigation of buildings, each of them dealing with a specific aspect of the problem. In the following subsections, there is a brief analysis of previous work on each aspect.

a. BIM

Building Information Modeling (BIM) is an emerging technology in the Architecture/Engineering/Construction (AEC) industry. BIM is a digital representation of the physical and functional characteristics of a building, which can serve as a shared knowledge resource for building information. Based on semantics and object oriented techniques, the BIM 3D modeling approach facilitates access to data about the building, including the objects with their features, used in the design, construction, and operation phases [3]. In addition, BIM's parametric design capability enables quick, interactive, and real-time design changes. BIM was not designed for applications in historical buildings, but a number of researchers have investigated how BIM itself, or its extensions, could be useful to this field. In particular, research conducted by Oreni et al. [5] illustrates the usefulness of switching from 3D content modelling to Historic Building Information Modelling (HBIM), to support the conservation and management of building heritage by proposing a library for the analysis of vaults and wooden beam flooring. Another study by Pauwels et al. [6] investigates the advantages of an alternative approach to BIM, called AIM (Architectural Information Modelling), for applications in building documentation for virtual heritage, combined with historical analysis tools.

b. AR visualization

Augmented Reality is a field of research that aims to create an environment where computer generated data are inserted into the user's view of a real-world scene. It plays a key role in improving and enriching the visualization of objects contextualized in a specific place. In literature, there are many different technologies based on different principles to implement tracking of Augmented Reality, but in this paper we will cite only Computer Vision, owing to its use of non-invasive tools.

Steps in visualizing 3D objects in Augmented Reality using Computer Vision include:

1. recognition of a marker (a.k.a. marker-based approach) or of an object in the scene (a.k.a. marker-less approach);
2. context aware methods for visualization in real-time of video and augmented contents that enable them to be used in a mobile setting.

Many studies conducted on the two topics have been well summarized in a recent survey conducted by Shoaib [7]. Both marker-based and marker-less approaches have been proposed in many commercial ready-to-use solutions [8]; however, a marker-less approach is not always possible because it requires specific lighting conditions and the availability of identifiable features in the scenario.

AR technology has developed in line with mobile technologies and often takes the form of application software that can be displayed on smartphones, tablets or even innovative AR glasses. Despite this, visualization in real-time can be a problem when using devices with low performance if it involves complex 3D models.

The most popular topics regarding AR visualization are interaction and Mobile Augmented Reality.

Feiner and Hollerer [4] have identified six basic technological AR components:

- **Computational platform** for processing and computing all relevant information needed to visualize objects in AR on the display.
- **Display** to present virtual objects to the user.
- **Registration of environment**. Registration of camera input and head orientation helps to align AR objects correctly with the real world.
- **Wearable input and interaction technologies** to enable user mobility and collaboration with other users.
- **Wireless networking** for instant communication with other people and central databases.
- **Data storage and access technology** to provide the user with all context relevant data in the environment intended for augmentation.

c. BIM and AR integration

Both BIM and AR integration have been investigated in many research studies related to facility management and tools for the AEC (Architecture Engineering Construction) industry. Koch et al. [10] have proposed a conceptual framework to support facility maintenance operators in performing daily on-site jobs combining Building Information Models and natural markers for AR-based maintenance support. Irizarry et al. [11] have proposed InfoSPOT, a mobile Augmented Reality (AR) tool for accessing information about the facilities where they manage maintenance. Woodman et al. [12] have proposed a software system for mobile mixed reality interaction with complex BIM models. Gheisari et al. [13] have explored the advantages of an approach using BIM and Mobile Augmented Reality in Facilities Management by conducting a survey among facility managers to acquire feedback. Hakkarainent et al [14] have proposed software architecture to provide mobile users with real-time access to CAD and BIM information by using augmented reality at the construction site. El Ammari has proposed a framework for collaborative BIM-based marker-less Mixed Reality (BIM3R), integrating CMMS (Computerized Maintenance Management Systems), BIM and video-based tracking in a BIM3R setting, to retrieve information based on user time and location, visualize maintenance operations, and support collaboration between the field and the office to enhance decision-making.

d. Our contribution

Many studies have been conducted on BIM applied to historical buildings, on AR and on the integration of BIM and AR technologies for facilities management and there is no doubt about their usefulness. To our knowledge, there is no previously published work applying these technologies to improve historical building investigation. It is therefore an area revealing a field that presents new challenges, due to the limited accessibility and use of non-invasive tools for analysis. This situation could greatly benefit from the availability of new tools, which would integrate and offer a contextualized view of analytical results using non-invasive tools directly on-site. The system addresses the following issues:

1. explore the problems of this approach when applied to historical buildings, and propose solutions;
2. compare this approach with the traditional one and evaluate advantages.

3. System overview

The main aim of the system is to create a tool to improve the investigation of historical buildings. The system has been developed in three main steps:

1. Integration of diagnostic data into BIM representation of the historical building;
2. Development of a software module to read BIM data;
3. Development of an Augmented Reality module to detect features of specific building parts or markers inside the historical building and *augment* visualization using BIM information.

The project includes a device to display real-time augmented viewing during the investigation, which should be used by the engineer or the architect during the indoor on-site analysis of the historical building.

Figure 1 represents the logical architecture of the complete system. This paper describes only the modules relating to the BIM building representation, diagnostic data integration into BIM and the adopted Augmented Reality technology. A description of each module developed for this research work is given in the following sub-sections.

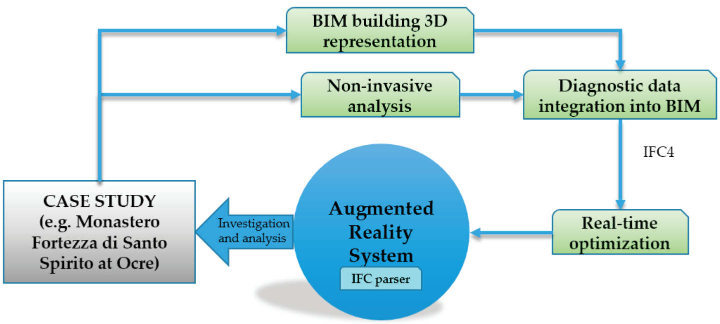

Figure 1. Logic architecture of the system

a. Diagnostic data integration into BIM

Integration of diagnostic data into BIM is crucial for the described system because it allows information to be added to each section, preserving the semantic value of the BIM representation. During the development phase of this module, our focus was mainly on merging different kinds of information by simplifying access for the end-user. To achieve this goal, a customized workflow was adopted with three main phases: BIM building representation, diagnostic data integration into BIM and the implementation of a parser to read BIM data. In the following sub-sections, there is a description of each phase.

BIM building representation

In this step, a 3D representation of the historical building was built using the commercial software Archicad. The result was a BIM representation of the building including many parts with semantic references. The software offers many exporting formats, among which there are proprietary and non-proprietary ones. One of the most adopted non-proprietary formats is the IFC (Industry Foundation Classes [3], an open standard data model developed by the International Alliance for Interoperability (IAI).

The choice of IFC data model allows the building geometry and materials property information to be exported using a BIM authoring tool; being an open standard, it can also be extended with new features to add new information if required. More specifically, the IFC-SPF was adopted for the BIM representation: this is a text format defined by ISO 10303-21 ("STEP-File") having file extension ".ifc". The basic SPF structure divides each file into a header and a data section. The header section has information about:

- the IFC version used;
- the application that exported the file;
- the date and time the file was exported;
- the name, company and authorizing person that created the file (optional).
- In the following text there is an example of a header of an IFC file.

```
HEADER;
FILE_DESCRIPTION((‘IFC 2x platform’),’2;1’);
FILE_NAME(
‘Example.ifc’,
‘2005-09-02T14:48:42’,
(‘The User’),
(‘The Company’),
‘The name and version of the IFC preprocessor’,
‘The name of the originating software system’,
‘The name of the authorizing person’);
FILE_SCHEMA((‘IFC2X2_FINAL’));
ENDSEC;
```

The data section contains all instances for the entities of the IFC specification. These instances have a unique (within the scope of a file) STEP Id, the entity type name and a list of explicit attributes. In the following text there is an example of a data section of an IFC file.

```
DATA;
#4= IFCPERSON($,’Undefined’,$,$,$,$,$,$);
#6= IFCORGANIZATION($,’Undefined’,$,$,$);
#10= IFCPERSONANDORGANIZATION(#4,#6,$);
#13= IFCORGANIZATION(‘GS’,’Graphisoft’,’Graphisoft’,$,$);
#14= IFCAPPLICATION(#13,’18.0.0’,’ArchiCAD-64’,
‘IFC2x3 add-on version: 3006 ITA FULL’);
#15= IFCOWNERHISTORY(#10,#14,$,.ADDED.,$,$,$,1425638738);
#16= IFCSIUNIT(*,.LENGTHUNIT.,.MILLI.,.METRE.);
#17= IFCSIUNIT(*,.AREAUNIT.,$,.SQUARE_METRE.);
#18= IFCSIUNIT(*,.VOLUMEUNIT.,$,.CUBIC_METRE.);
```

Diagnostic data integration into BIM

The integration of diagnostic data into BIM requires the use of a customized approach because, at present, the adopted software does not support this feature natively. As previously anticipated, the use of IFC offers the possibility of adding new fields to extend the file format with other features. For each part of the representation, studies carried out with non-invasive tools were added using a customized field of the BIM. Figure 2 shows an image of thermal camera analysis (left) and the layout of the building with the indication (right) of the location related to the acquired data.

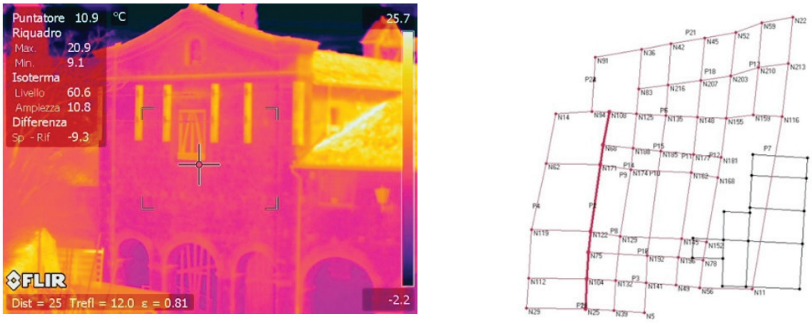

Figure 2. Thermal image and building layout

To extend the primary data structure with new information, ***IfcProperty*** and ***IfcPropertySet*** custom properties were used. Table 1 shows an example related to the definition of a set of properties for Infrared thermal imaging of the historical building.

Table 1. Set of properties for thermography

Investigation	Thermography
Name of property set	Thermography building
	Property name
	filename
	note
	author
	date
	scale
	camera model
	spatial resolution
	Thermal resolution
	accuracy
	Spectral range
	FPA
	Sensor resolution
	Measuring range

IFC parser implementation

In order to implement integration of the resulting ifc file with the rest of the system, a C++ ifc library was adopted. Among the various commercial and open source tools available for working with IFC data [17] our choice was IfcPlusPlus, an open source C++ library that offers classes to simplify reading and writing of IFC files in STEP format. The main features of the library are, availability of easy and efficient memory management tools; the availability of a parallel reader for rapid parsing on multi-core GPUs (Graphics Processing Unit) and integration with the rendering engine Open-SceneGraph [15] for visualization purposes.

b. Software architecture

As shown in Figure 3, the system is modular to allow reuse of components and includes four main modules:

- The **BIM module** software, which is responsible for handling and accessing BIM data including the geometric information of the model and diagnostic data.
- The **ArModule** software, which is used for object recognition and tracking. It is based on marker and marker-less algorithms depending on the features of the reference scenario. The tracking algorithms were implemented using the OpenCV library [16] while visualization was implemented using the Open-SceneGraph library [15];
- The **GUI Module,** which provides a user interface to browse and visualize data, handling user interaction through different types of widgets;
- The **DB Module**, which is responsible for handling and accessing user profile data and was developed using the Soci library [18].

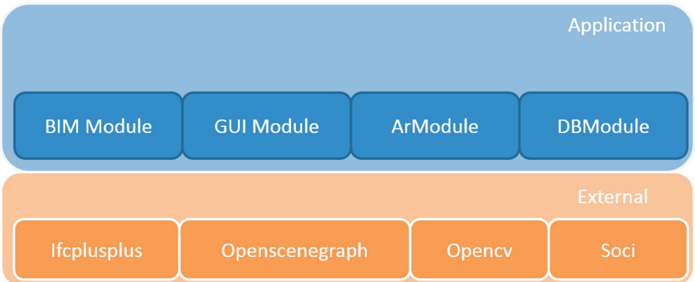

Figure 3. Software architecture

c. AR visualization

Hardware

In order to develop the ArModule, a pair of 3D glasses and a pc tablet were used, as shown in Figure 4. The following sub-sections provide an overview of each device, and explain why they were chosen.

***Vuzix Wrap™ 920AR*:** The Vuzix Wrap 920AR eyewear is composed of two parts:

– a stereo camera system to capture the real world;
– a display that shows the captured scene to the user with the visual equivalent of a 67-inch display seen from a distance of 10 feet (3m).

The twin camera system of the Wrap 920AR provides two video sources, each connected to a PC as a standard USB video camera device. Each camera captures 640 x 480 VGA video at a speed of 30 frames per second.

The display capabilities of the Wrap 920AR can be used on virtually any composite compatible device. In order to use it in an augmented reality system, it can be connected to a Windows-based personal computer through the included Wrap VGA Adapter. The image produced by the eyewear, which can be displayed in standard 2D or 3D, can be augmented with any form of computer-generated data in the form of text, still images, or video.

Asus Eee Slate EP121: The Asus Eee Slate is a device with high performance and portability, equipped with an Intel ® Core i5 ™, a large ultrasensitive touchscreen Wide Screen (12.1", 1280 x 800 pixel), which can be used freehand or with an input-precision stylus. It runs Windows 7 Home Premium 64 bit, weighs 2.5 lbs and its battery life is up to 3.5 hours.

The device uses SSD memory for storage instead of a traditional mechanical hard drive, which is useful to speed up performance of developed software, thus ensuring its use in real time. The device can be connected to the chosen eyewear by means of two USB ports, Atheros WiFi 802.11b/g/n and a mini-HDMI port.

These features make this device suitable for supporting video analysis during exploration campaigns. Coupled with Vuzix Wrap 920AR eyewear via usb, it can guarantee the direct acquisition and real-time processing of the scene.

As an alternative to using the stylus to control the PC tablet, we experimented the use of a mobile phone as a mouse replacement. In particular, our experimental system uses Bluetooth communication to control the PC tablet through the smartphone touch screen, allowing the user to select a particular region of interest (ROI) on the screen in order to process only a specific area of the scene.

Figure 4. Devices used for experimental system

Software methods and technologies for tracking

In visual tracking, the system determines the pose estimation based on direct observations of the scene. In an environment without robust features it is impossible to recognize a predefined pattern model based solely on visual observations of the scene. One solution to overcome these challenges is to add an easily detectable predefined image inside the environment and use computer vision techniques to identify it. This ‘marker’ is a sign or image a computer system can detect in a video using image processing, pattern recognition and computer vision techniques. Once detected, it defines the pose estimation: this approach is called marker-based tracking.

Another approach for visual tracking is to use feature-based methods, in which there is a model of the scene or part of the scene (e.g. an image pattern). It compares visual observations with the model and finds the best match, which defines the pose estimation. In feature-based tracking, the system detects optical features exclusive to the images and acquires information about the environment by observing movements between frames.

In our ArModule, feature-tracking and marker-based tracking are mutually non-exclusive. In fact, marker-based methods outperform feature-based methods in certain cases (e.g. environments with large white walls, have almost no features and therefore, feature tracking is impossible or at the least, very unreliable), while the markerless approach is used for visual tracking in recognizable environments.

The Augmented Reality module was developed following a processing pipeline, consisting of the following stages:

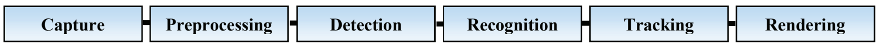

Figura 5. Stages of AR module development

- *Capture*: in the first step the capture device acquires the scene in real-time; in this experimental system the Vuzix Wrap 920AR was used;
- *preprocessing*: all operations in this stage aim at improving image data, removing undesired distortions and/or enhancing certain image features, needed for subsequent processing steps;
- *detection*: in this stage, the pipeline applies both a feature detection and an extraction algorithm;
- *recognition*: once the features are generated by the detection stage, a matching algorithm is used to match the features against a database of known patterns;
- *tracking*: this stage uses tracking-by-detection algorithms, which allows tracking of known patterns through a detection analysis on sequential frames;
- *rendering*: the data collected in the previous steps are used to *augment* the scene by adding information about the object of analysis identified in the scene. For example, BIM property information could be added to the *augmented* scene when a fresco is identified.

The recognition and tracking steps also include a pose estimation, which allows retrieval of the spatial relationship between the user’s point of view and the virtual object by means of identification, in the scene, of common features (points , lines, spots) and, through knowledge of these features (appearance, size, position in 3D space). The result is a qualitative measure of 6DoF (Degree of Freedom) of the object in the actual scene, which is crucial during the rendering step, to display the position and orientation of the augmented content in a consistent way.

The structure of the software module, which handles the pose estimation, can be conceptually divided into two stages: learning phase and detection phase. Prior to the first phase, a camera calibration step is required to avoid issues related to image distortions resulting from the optics used. The first phase extracts and identifies the scene storing the descriptors of its structural elements. In the second phase, all the stored elements are used to perform a matching with the elements identified in the scene; at the end, the pose of 3D object reference is estimated. Figure 6 illustrates a flowchart representing these two phases.

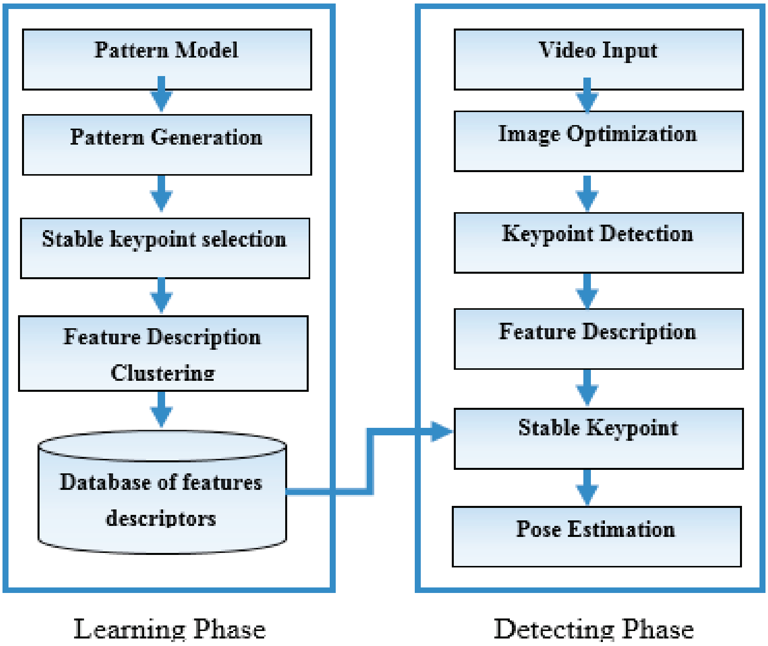

Figure 6. Flowchart of learning and detection phases

In order to address research and development towards algorithms for key-point detection, features description and key-point matching, different vision-based techniques were tested.

In particular, the following algorithms were taken into consideration:

Speeded-up Robust Features (SURF): SURF was presented by Bay et al [19]. It is a local feature detector and descriptor that uses an integer approximation of the determinant of Hessian blob detector to detect interest points. Its feature descriptor is based on the sum of the Haar wavelet response around the point of interest. The descriptor can also be obtained in the form of a vector, based on the distribution of the intensity content within the local image regions of the points. The SURF detector and descriptor utilize the integral images to reduce computation time, which makes them almost three times faster than the SIFT detector and descriptor. This technique ensures that the points of interest are robust against image rotation and scale.

Scale-Invariant Feature Transform (SIFT): SIFT was published by David Lowe [20]. In the first step of the algorithm, the local maxima or minima of the Difference of Gaussians (DoG) are used to identify potential interest points, which are invariant to scale and orientation. Subsequently, points that have low contrast or are poorly localized on an edge are deleted from the list of key-points. Using the remaining key-points, a consistent orientation is assigned. When the key-points are located and assigned with dominant orientations, the feature vectors are calculated. This technique can robustly identify patterns even under partial occlusion, since the SIFT feature descriptor is invariant to uniform scaling, orientation, and partially invariant to related distortions and changes in illumination.

Oriented FAST and Rotated BRIEFF (ORB): ORB is based on the visual descriptor BRIEF [21] (Binary Robust Independent Elementary Features) and the FAST [22] key-point detector with several improvements. Both these techniques are attractive due to their good performance and low cost. In the first phase, it uses FAST to find key-points, and then it applies the Harris corner measure to calculate and remove potential edge points. At this stage, the orientation of each corner point is estimated based on the centroid intensity in regions localized in points recognized as corners. In order to improve rotation invariance, the central moments are computed making the ORB descriptor rotation-invariant. In addition, another benefit of using the ORB detector and descriptor is their computational efficiency when compared with the SIFT and SURF feature detectors and descriptors.

Features from Accelerated Segment Test (FAST): FAST was proposed by Rosten and Drummond [22]. It is a corner detection method that can be used to extract feature points and to track and map objects in many computer vision tasks. The FAST detection procedure includes two main steps: in the first step, the potential corner points in an image are classified with a segment test; in the second step, a score value is calculated at each potential corner point. The score values are used to remove the false corners classified previously. In general, the most promising advantage of the FAST corner detector is its computational efficiency. As its name states, it is undoubtedly fast, faster than many other well-known feature extraction methods, such as the difference of Gaussians (DoG) used by SIFT and Harris. This technique is consequently well-suited for real-time video processing application because of its high-speed performance.

In order to evaluate the performance of detectors and descriptors, we investigated the speed and quantity of features extracted by each method, in conjunction with the accuracy and speed of extraction and matching of the descriptors. All the features were obtained with default parameters given by their implementation. In order to evaluate the performance of various algorithms in quantitative terms we used some selected image patterns and scene images. In particular, we used a pattern size of 347 x 246 pixels, which was identified in a scene image measuring 640 x 480 pixels.

For each algorithm we extracted the number of features, the number of correct matches and the processing time; then a mean was calculated related to all the sets of patterns and scene images. The obtained results are summarized in Table 2.

Table 2. Algorithms performance

Detector	Descriptor	Pattern Features	Scene Features	Correct Matches	Features Detection (ms)	Descriptors extraction (ms)	Descriptors matching (ms)	Total Time (ms)
SURF	*SURF*	169	1014	158	53	52	3	112
SIFT	*SIFT*	408	2312	322	167	241	14	425
ORB	*ORB*	408	500	24	8	6	3	20
FAST	*ORB*	1102	5226	960	3	13	58	78

Each detector-descriptor set showed different results. In the following items, there are some considerations and comparisons on performance obtained by the algorithms in each step:

- SIFT: the most time-consuming step in SIFT is description, followed by detection. Because of its high computing complexity, SIFT spends most of the time extracting and describing features. The matching process does not take long and the matching algorithms for vector description are efficient.
- SURF completes detection and description in almost the same amount of time. Compared to SIFT, the processing time is significantly reduced. The matching phase also takes only a short time.
- FAST is one of the most efficient feature detectors. However, the many detected feature points lead to huge time consumption for the matching process, despite the fact ORB is a binary descriptor that makes matching of the binary description easier and faster than vector description.
- ORB: all three steps in ORB require almost the same amount of time, and complete processing in a fairly short time. Compared to other descriptors tested in this experiment, ORB performs much better than others.

The advantage in terms of processing speed due to its use of binary description, is clearly demonstrated in this case.

The application processes the real-time scene frame by frame, and only when the whole image matching process is finished for the current frame is the next frame then processed. This mechanism causes a delayed display when the entire matching phase takes longer than the frame rate of the video sequence acquisition. Display lag is particularly evident in SIFT. Although the FAST ORB optimizes some steps, it is still unable to achieve the requirements of real-time applications.

The ORB-ORB processing speed is quite fast, with no display lag observed and video sequences played back smoothly. In matching results, SIFT and SURF show outstanding performance, a considerable number of detected feature key-points, and the matching result is accurate and robust. Although the ORB-ORB detects less feature key-points compared to SIFT, SURF and FAST, it nevertheless obtains a sufficient number of correct matches.

In conclusion, despite their high accuracy and robustness, SIFT and SURF are unsuitable for use in a real-time application because of the long processing time. ORB-ORB satisfies the stringent real-time requirements, shows good performance and is the better trade-off in terms of accuracy and real time performance.

d. AR and BIM integration

In order to integrate AR and BIM technologies, each pattern identifiable through AR was connected to a specific identifier available in the BIM model. In this manner, by using the BIM reader, AR can retrieve additional information related to the identified pattern and can show it to the user superimposed on the real-time visualization in the glasses.

Figure 7 shows the experimental system in which the user wears the eyewear and is able to view all the information related to the historical building through the glasses and can interact with the application using a smartphone to change the type of data to be visualized.

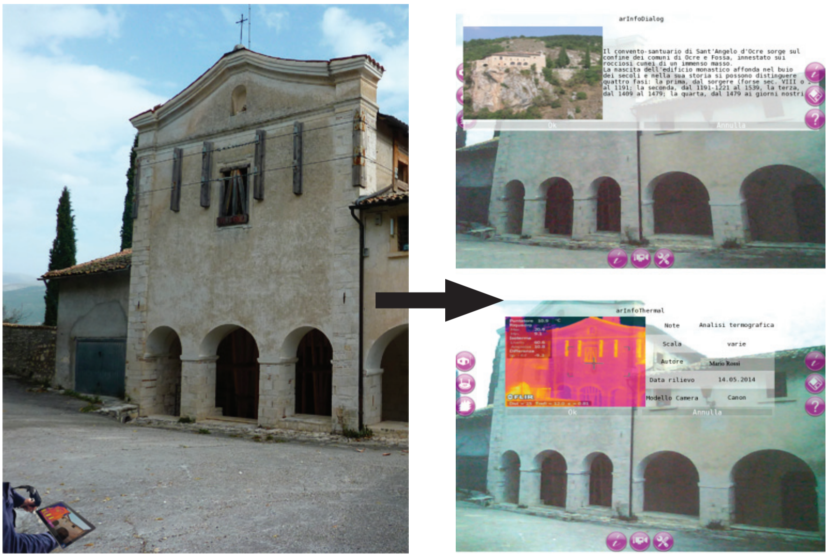

Figure 7. Experimental system showing data related to building and infrared camera data

4. Conclusions and future work

An experimental system improving the investigation of historical buildings was developed focusing on the following aspects:

– BIM representation;
– integration of output from non-invasive tools into BIM;
– Augmented Reality visualization.

Extensive tests performed by engineers and architects have revealed that such a system may enhance the investigation of historical buildings. The system was found to be helpful to contextualize information for indoor analysis of the building and to simplify access to BIM information.

Further research is required to eliminate the use of markers for Augmented Reality completely and standardize a new BIM format (or extensions) including output from non-invasive tools. In order to improve recognition in particular conditions, more research must be done into 3D features recognition which, in the coming months, will be supported by the release of new mobile consumer devices integrating an RGB-D camera (e.g. Intel RealSense technology, Microsoft Hololens, and Google Tango Project). This type of camera enables modeling in 3D indoor environments [23], opening up new scenarios for Augmented Reality features detection through mobile devices. In addition, standardization and integration of new data in BIM or the creation of a new standard for cultural heritage could simplify reusability of acquired data and reconstructed buildings.

Acknowledgments
Research activities in this paper are partly funded by the research program PONREC PROVACI (Technologies for seismic protection and valorization of cultural heritage). Grant Cod. PON01_02324.

References

[1] Fischetti, D. C. (2009). *Structural Investigation of Historic Buildings: A Case Study Guide to Preservation Technology for Buildings, Bridges, Towers and Mills*. John Wiley & Sons.

[2] Wang, X. (2009). Augmented reality in architecture and design: potentials and challenges for application. *International Journal of Architectural Computing*, *7*(2), 309-326

[3] Eastman, C., Eastman, C. M., Teicholz, P., & Sacks, R. (2011). *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors*. John Wiley & Sons.

[4] Höllerer, T., & Feiner, S. (2004). Mobile augmented reality. *Telegeoinformatics: Location-Based Computing and Services. Taylor and Francis Books Ltd., London, UK*, *21*.

[5] Oreni, D., Brumana, R., Cuca, B., & Georgopoulos, A. (2013, July). HBIM for conservation and management of built heritage: Towards a library of vaults and wooden bean floors. In *CIPA 2013XXV International Symposium, ISPRS Annals* (Vol. 164, pp. 1-6).

[6] Pauwels, P., Verstraeten, R., De Meyer, R., & Van Campenhout, J. (2008). Architectural Information Modelling for Virtual Heritage Application. In *Digital Heritage–Proceedings of the 14th International Conference on Virtual Systems and Multimedia* (pp. 18-23).

[7] Shoaib, H. A Survey of Augmented Reality. *interactions*, *24*, 34.

[8] Amin, D., & Govilkar, S. COMPARATIVE STUDY OF AUGMENTED REALITY SDK'S.

[9] Abboud, R. (2014). Architecture in an Age of Augmented Reality.

[10] Koch, C., Neges, M., König, M., & Abramovici, M. (2012). BIM-based augmented reality for facility maintenance using natural markers. In *Proceedings of the EG-ICE International Workshop on Intelligent Computing in Engineering*.

[11] Irizarry, J., Gheisari, M., Williams, G., & Walker, B. N. (2013). InfoSPOT: A mobile Augmented Reality method for accessing building information through a situation awareness approach. *Automation in Construction*, *33*, 11-23.

[12] Woodward, C., & Hakkarainen, M. (2011). *Mobile mixed reality system for architectural and construction site visualization*. INTECH Open Access Publisher.

[13] Gheisari, M., Goodman, S., Schmidt, J., Williams, G., & Irizarry, J. (2014). Exploring BIM and mobile augmented reality use in facilities management. In *Proceedings of the Construction Research Congress* (pp. 1941-1950).

[14] Hakkarainen, M., Woodward, C., & Rainio, K. (2009, October). Software architecture for mobile mixed reality and 4D BIM interaction. In *Proc. 25th CIB W78 Conference* (pp. 1-8).

[15] Burns, D., & Osfield, R. (2004). Open scene graph a: Introduction, b: Examples and applications.

[16] Bradski, G. (2000). The opencv library. *Doctor Dobbs Journal*, *25*(11), 120-126.

[17] Dhillon, R. K., Jethwa, M., & Rai, H. S. (2014). Extracting Building Data from BIM with IFC. *Int. J. on Recent Trends in Engineering and Technology*, *11*(1).

[18] Sobczak, M. (2004). A simple oracle call interface. *Dr. Dobb\'s Journal*, *29*(12), 52-55.

[19] Bay, H., Tuytelaars, T., & Van Gool, L. (2006). Surf: Speeded up robust features. In *Computer vision–ECCV 2006* (pp. 404-417). Springer Berlin Heidelberg.
[20] Lowe, D. G. (1999). Object recognition from local scale-invariant features. In-*Computer vision, 1999. The proceedings of the seventh IEEE international conference on* (Vol. 2, pp. 1150-1157). Ieee.
[21] Calonder, M., Lepetit, V., Strecha, C., & Fua, P. (2010). Brief: Binary robust independent elementary features. *Computer Vision–ECCV 2010*, 778-792.
[22] Rosten, E., & Drummond, T. (2006). Machine learning for high-speed corner detection. In *Computer Vision–ECCV 2006* (pp. 430-443). Springer Berlin Heidelberg.
[23] Henry, P., Krainin, M., Herbst, E., Ren, X., & Fox, D. (2012). RGB-D mapping: Using Kinect-style depth cameras for dense 3D modeling of indoor environments. *The International Journal of Robotics Research*, *31*(5), 647-663.

Biographical notes

Francesco Chionna is a computer science engineer. He has many years' experience of working as a researcher, and four years as a manager of other engineers and scientists. He has managed industrial and military research projects focused on developing software and systems for virtual and augmented reality applications used by several Universities and private companies. He has hands on experience in all stages of system development, including requirements definition, design, architecture, coding, testing and delivery to customer. His research focuses on ICT innovations for construction applications including visualization technologies, image processing and machine learning.

Francesco Argese is a computer science engineer. After graduating with a master degree at the University of Salento, he began working as a researcher at the Division of Computer Engineering of the CETMA Consortium, Engineering, Design & Materials Technologies Centre. Over the years he has gained important experiences in the ICT fields of Software Engineering, Virtual Reality, Augmented Reality and collaborative systems by conducting research and achieving results of interest in several research projects of national importance.

Vito Palmieri is a Computer Science engineer. After graduating from the Polytechnic University of Bari, he started working as a researcher at the Division of Computer Engineering of the CETMA Consortium, Engineering, Design & Materials Technologies Centre. His research interests are mainly focused on Virtual Reality, Augmented Reality, Human Machine Interaction and Computer Vision.

Italo Spada is senior researcher at the CETMA Consortium in the field of new media and interaction applied to cultural heritage, industrial design, scientific research and training. He is currently coordinating national and international projects dedicated to new technologies, edutainment, entertainment, virtual archeology and museum interaction. He works mainly on the following areas: technologies for 3D buildings, methodologies and tools for the optimization of different complex geometric patterns, immersive and interactive space design, dynamic real-time tracking of the human body, 3D rigging, augmented reality mobile applications and interaction with dynamic 3D digital contents.

Lucio Colizzi is an Information Technology engineer. After many years of experience in ICT, robotics, Virtual Reality and data processing and modeling, in 2001 he became the ICT department Director of CETMA. He has co-ordinated important national research programs and in the last ten years has also been coordinator on several projects in the field of development of technologies for cultural heritage. He has obtained many post-graduate qualifications: BPR, Concurrent Engineering and Quality Function Deployment, STEP –ISO 10303, Simple ++, eM-Plant, eM-Planner, Informix Dynamic Server Administration and Performance Tuning, Design for Manufacturing & Assembly, Object Oriented design with UML, Microsoft certifications: C#, ADO.NET, ASP.NET; XML Web Services.NET; PROJECT MANAGEMENT (Bocconi University). As a result of his many interests he has taught “Project Management and Group Dynamics” as Adjunct Professor at the universities of Bologna and Lecce.