An approach to the potential of HBIM models in the public use of heritage

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Abstract: Most heritage assets are usually made available for public use. Because any loss or deterioration can cause the asset irreversible damage, the greatest challenge in managing heritage is building a sustainable and responsible relationship between visitors and the heritage asset, while also making it intellectually accessible to foster appreciation for it and make it into an object of conservation efforts.

Up to now, public visits have been managed using classic techniques, but recent developments in Historic Building Information Modeling (HBIM) have proven it to be worthwhile as a collaborative system that leverages technological tools to aide in the management of heritage assets over their life spans, in such aspects as managing visitors, recreational carrying capacity especially, preventative maintenance, interpretation programs and info-graphical media for educational purposes.

The objective of this study is to identify HBIM's potential for improving the efficiency of processes involved in managing the public use of heritage as part of a future HBIM protocol. The methodological approach used for this research is Design Science Research (DSR). The data collection techniques used were semi-structured interviews, visits to heritage sites and the analysis of specific documentation. The results indicate that HBIM can improve and optimize traditional data collection processes and information management since said information is often sparse, outdated, or duplicated. It is also worth noting that HBIM can be useful for more efficiently monitoring the visitors *in situ*, thereby contributing to better conservation of heritage and an enhanced tourist experience, in addition to helping educate the public as to the importance of heritage assets.

Keywords: BIM, HBIM, heritage, public visit management, carrying capacity, interpretation, preventative maintenance, education.

1. Introduction

Cultural heritage is made up of artifacts from the past that we wish to pass on to future generations because of their social value and the way they safeguard identity (UNESCO, 37 C / 4, 2014). Most heritage buildings are usually outfitted for public visits or some other use. The main function of heritage management is to transmit both the asset's significance to visitors and the host community, as well as the reason it must be conserved, as indicated by the International Cultural Tourism Charter (ICOMOS, 1999). In addition, public use contributes to its ongoing maintenance and reinforces the ties between society and the monument or site; for this reason, it is presented as an opportunity for revitalizing, appreciating and boosting heritage assets (Viñals *et al.,* 2017). In all cases when visitors enter a heritage asset, it must be remembered that they are moving around in a fragile space containing cultural value which must be preserved. The challenge for conservators is to properly manage the relationship between the heritage and its visitors, and to ensure the asset is conserved (Villafranca & Chamorro, 2007). The scientific literature has made interesting contributions from different perspectives on how to understand the duality of heritage-public use. UNESCO (2014) has made important contributions in this regard to encourage the effective conservation of an asset's heritage values for the purpose of preserving it for present and future generations. For its part, ICOMOS (1999), in the International Charter on Cultural Tourism, reminds us that heritage is a resource that is subject to destruction, disappearance or irreversible loss and, for that reason it should not be made available to mass visits since excessive or poorly-managed tourism can put it in danger.

From the scientific works analyzed, it has also been observed that public use issues consider how certain tools or technical planning and management tools (plans, programs, etc.) might be used handle recreational carrying capacity and visitor flow management, preventative maintenance, interpreting heritage, and dissemination (Figure 1).

Figure 1. Instruments for planning and managing public use of heritage

Recreational carrying capacity is an instrument for planning and managing public visits in such a way that limits on use are set according to the number of visitors to ensure firstly, that the heritage is preserved under the desired conditions, and secondly, the tourist experience is of a high quality (Viñals *et al.*, 2014; 2016).

Preventative maintenance focuses on minimizing risk of deterioration, thus avoid losses or costly restoration treatments, as indicated in the National Plan for Preventative Maintenance (Ministry of Education, Culture and Sports of Spain, 2011). The strategy for preventative maintenance includes aspects such as sustainability, i.e. the continuous maintenance and optimization of resources, and accessibility for raising awareness and knowledge of the heritage

throughout society. It must be remembered, as has been mentioned, that public visits may cause damage to heritage assets (Figure 2), some of which can at times be irreversible.

With regard to heritage interpretation, it should be noted that the ICOMOS Charter for the interpretation and preservation of cultural heritage sites (ICOMOS, 2005) recommends that visitors be made aware of the site's significance through the interpretation of heritage. The interpretation program is therefore very useful for managers since it helps teach about the asset's significance, it creates sensations and emotions and, therefore, is able to create feelings of appreciation for the heritage in visitors (Ham, 1992).

Lastly, it is important to remember the importance of teaching about heritage, through both personnel (guides-interpreters, reporters, etc.) and material methods (information represented graphically such as tourist maps, brochures, panels, infographics, etc.), which are important drivers in the site's strategic communication plan (Figure 2).

Figure 2. Educational panel for the San Juan del Hospital Ensemble in Valencia

There is also extensive literature on Building Information Modeling's (BIM) capacities. Kemp (2014) describes it as an opportunity to be more efficient in the building sector, and a UK Goverment publication (2015, p.10) defines it as “a collaborative way of working, underpinned by the digital technologies which unlock more efficient methods of designing, delivering, and maintaining physical built assets. BIM embeds key product and asset data in a 3D computer model that can be used for effective management of information throughout an assets lifecycle- from earliest concept through to operation”. In short, BIM leverages all the stakeholders’ qualities to optimize project results and its stages, while simultaneously providing greater and faster access to complete information, fostering rigorous collaboration, improving decision-making, making the most of innovative technologies and allowing the building’s complete life cycle to be incorporated. (Edwards, 2017).

In recent years, there has been growing interest in studying how to implement BIM in heritage buildings, which is called Heritage BIM (HBIM). Oreni *et al.* (2014) have defined HBIM models as a useful tool for storing, centralizing, remotely accessing and sharing information about historical buildings from all the different disciplines involved and throughout their life cycle. In the scientific literature, there is a great deal of evidence that HBIM can improve the conservation of architectural heritage throughout its life cycle (Garagnani *et al.*, 2013), its registration and documentation (Casu and Pisu, 2016), knowledge and management (Lo Turco *et al.*, 2016; García-Valldecabres, 2016), maintenance (Fassi *et al.*, 2016) and education (Brumana *et al.*, 2013). It should be noted that HBIM is a very powerful tool for documenting and recording heritage (Hawas and Marzouk, 2017) via data collection with a laser scanner (Quattrini *et al.*, 2015), and it is especially useful for recording inaccessible heritage, to get an overall vision and understanding of the building (Counsell and Taylor, 2017) and to analyze the historical building processes (Guedelon, 2015). It can therefore be stated that it can resolve the general problem shared by most heritage sites, information management (Hegazy, 2017).

Beyond these functions, Fassi *et al.* (2016) propose using HBIM to manage maintenance work in combination with immersive visualization techniques (virtual reality -VR- and augmented reality -AR-). Simulations can be conducted using these functions to quickly evaluate alternatives and facilitate decision-making (Khalil, 2017), while also performing simulations on energy efficiency (Edwards, 2017) under different climatic conditions and for different activities.

In addition, various authors and institutions have developed protocols for new buildings (Chaves *et al.*, 2016) and have passed them on automatically for use in the heritage sector, though without considering the uniqueness of these buildings. It was the Council on Training in Architectural Conservation (2016) that developed the first HBIM cycle diagram applying norms for conserving heritage such as the British Standard BS 7913 (2013) and the "*Guidelines for Education and training in the conservation of Monuments, Ensembles and Sites*" (ICOMOS, 1993). In the United Kingdom, Historic England (2017) published the guide "*BIM for Heritage*" where it provides definition for HBIM Levels of Development (LOD). The most recent protocol is one provided by Jordán *et al.* (2018) shown in Figure 3, which shows the complete cycle diagram and where the use phase includes the functions: Maintenance and preservation (7) and Heritage education/culture dissemination (8). In their conclusions, however, they highlight the need for further in-depth studies on this phase of use, especially on those aspects dealing with preservative maintenance and heritage diffusion.

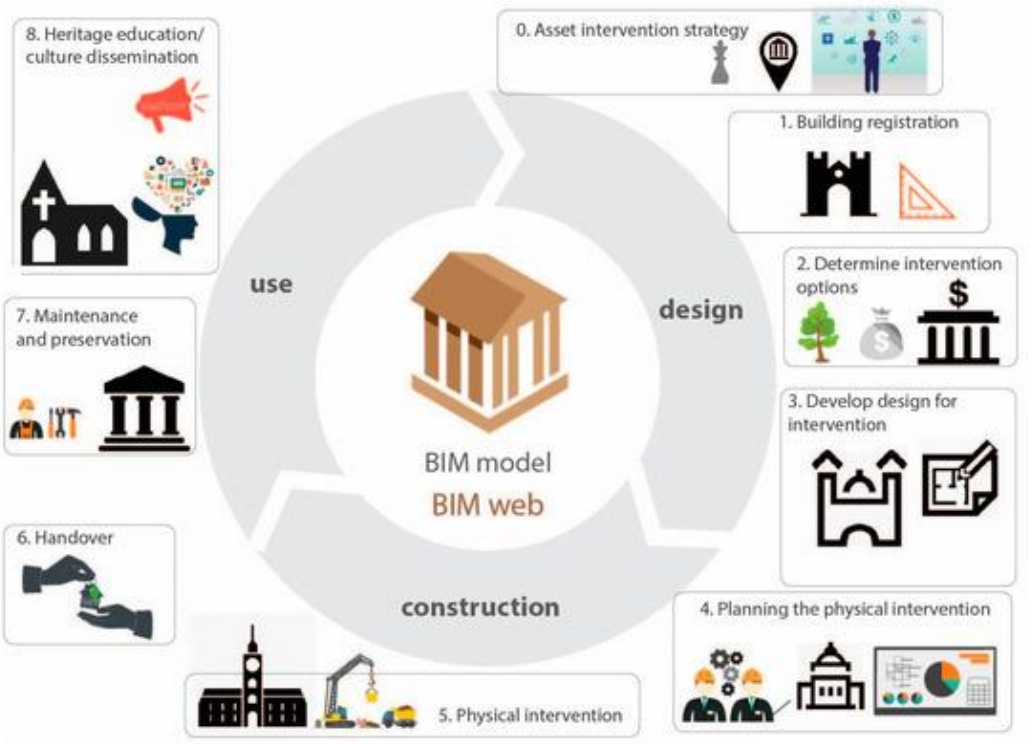


Figure 3. HBIM overview protocol (Jordán *et al.,* 2018)

Despite all of HBIM's capacities, there is no HBIM protocol that adopts a holistic approach to the management of public visits with regard to physical and intellectual access and visitors.

2. Research Objectives and Methodology

The purpose of this research is to address the study of HBIM's potential for managing the public use of heritage.

This work aims to establish those HBIM functions that can be assigned to the preliminary stage of analysis and that focus on identifying and understanding the issue of physical and intellectual and emotional access to heritage.

The methodological approach to be adopted for this research is Design Science Research (DSR). The mission of DSR is to develop an innovative solution (Holmström *et al.*, 2009) or artifact to solve a practical problem or to improve performance (Van Aken, 2004, Vaishnavi & Kuechler, 2007). The developed solution or artifact should undergo an empirical evaluation to see if it works (Holmström *et al.*, 2009). These authors divide the methodological process into two stages: 1. Solution incubation, which consists of identifying the problem and understanding it; and 2. Solution refinement, which consists of three steps: developing a solution, implementing the solution and evaluating the solution. This evaluation considers the artifacts' efficiency and effectiveness and their impact on the environment and users (March & Smith, 1995).

This study, as mentioned, will address and present the results of the first stage of analysis (Figure 4).

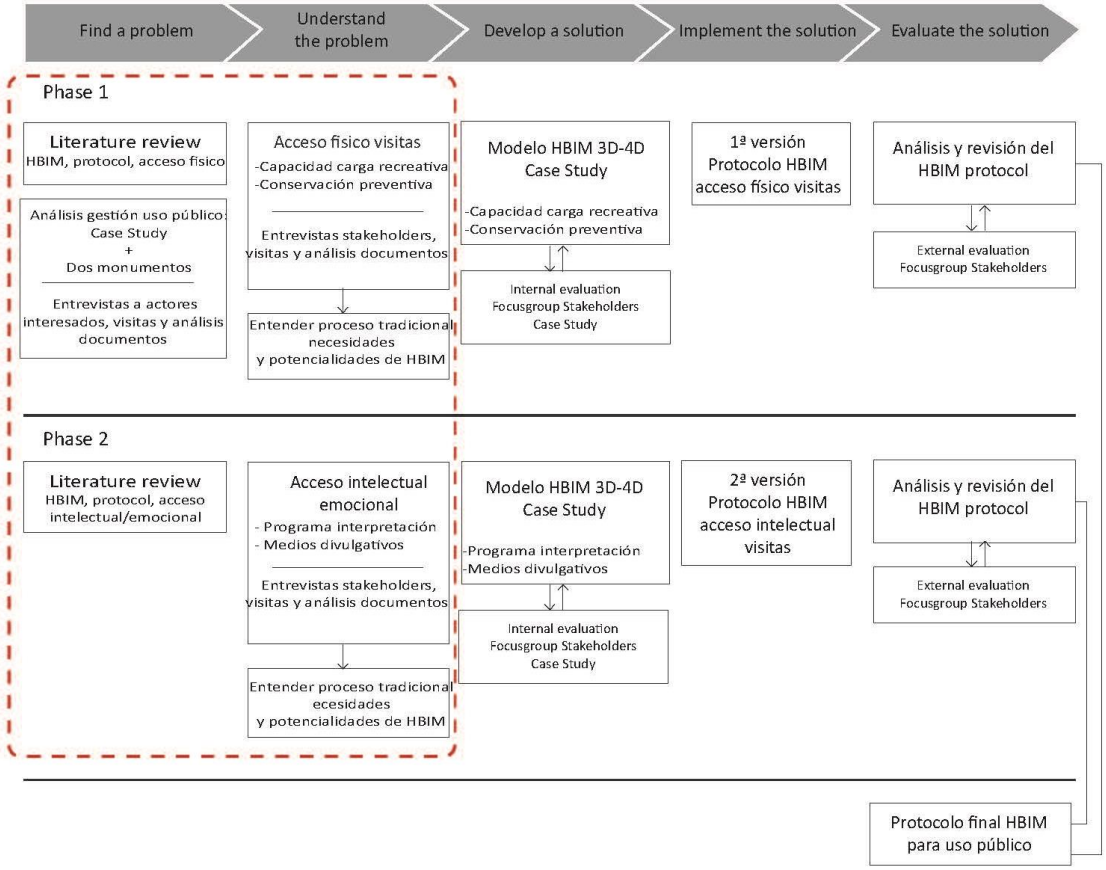


Figure 4. Overview of the research design. The dashed line indicates the stages of the study to be analyzed here.

To identify the problem, a review was conducted on the scientific literature on BIM, HBIM, heritage management, HBIM for the physical management of public use and BIM-HBIM protocols. The search was performed using scientific search engines, databases, digital libraries and scientific journals. In total, the following were analyzed: 21 articles from scientific journals, 17 conference proceedings, 5 books and 2 doctoral theses. Three case studies were visited (San Juan del Hospital in Valencia from the 13th century, the Monastery of the Descalzas Reales in Madrid from the 16th century and the Cerralbo Museum in Madrid from the 19th century). There were 5 unstructured interviews with stakeholders (museum conservator, architectural conservator, cultural manager, guide and secretary), and documentation about managing visits was analyzed. The interview questions were about traditional work processes, the functions of the agents involved, information flow, needs and the potential of HBIM.

The second phase of this stage entailed gaining in-depth understanding of the problem of the physical management of visits. For this purpose, 3 semi-structured interviews were conducted with specialists in recreational carrying capacity (managers of international monuments), such as the Alhambra in Granada. (Spain), the Cathedral of Santiago de Compostela (Spain), the Archaeological Park of Petra (Jordan), the Fort Santiago - Chikly (Tunisia) and 1 interview in preventative maintenance in the Institute of Cultural Heritage of Spain; in addition, documentation about the specific subject was analyzed. The questions asked about traditional work processes, functions of the intervening agents, information flow, needs and the potential of HBIM.

Regarding how HBIM might potentially facilitate visitors' intellectual and emotional access, a review of the scientific literature was performed (20 scientific articles, 15 conference

proceedings, 3 books and 2 doctoral theses), and 2 semi-structured interviews with specialists in interpretation programs and infographic media, in addition to an analysis of specific documentation. As in the first phase, questions were asked about the traditional work processes, the functions of the intervening agents, information flow, needs and potential of HBIM.

The work carried out made it possible to identify the functions of the stakeholders, how they relate to each other, how to represent the work in processes flowcharts, and to identify the needs and potentials of HBIM for these functions.

3. Results

A review of the literature has shown there is a lack of general studies and protocols dealing with public use management using HBIM from a holistic approach, as anticipated.

As far as recreational carrying capacity and managing visitor flows, it is worth noting that there are no specific studies on HBIM use on this issue either, though there is growing interest in integrating dynamic monitoring data in BIM (Niskaen et al., 2014). Likewise, Walton Basin (CPAT & Smith 2014) combined data from security cameras in real time with web models based on VR, and in the CADW project (2017) sensors were used to collect data from the Heritage Cottage (Wales, United Kingdom). Kingdom) in real time. The challenge would be to filter and analyze this dynamic data, so as to give heritage buildings the capacity for intelligent automatic response (Counsell, 2017).

After analyzing the literature and the answers from the interviews with experts about recreational carrying capacity, the results provide information about the functions of the stakeholder leading the activity and those of other stakeholders taking part in both the traditional processes as well as in identifying the needs and potential of HBIM (Figure 5). Following the indications of Simon (2006), given that the problem at hand is related to the interactions between and within the subsystem of the public use management, the corresponding flow charts have been developed (Figure 6).

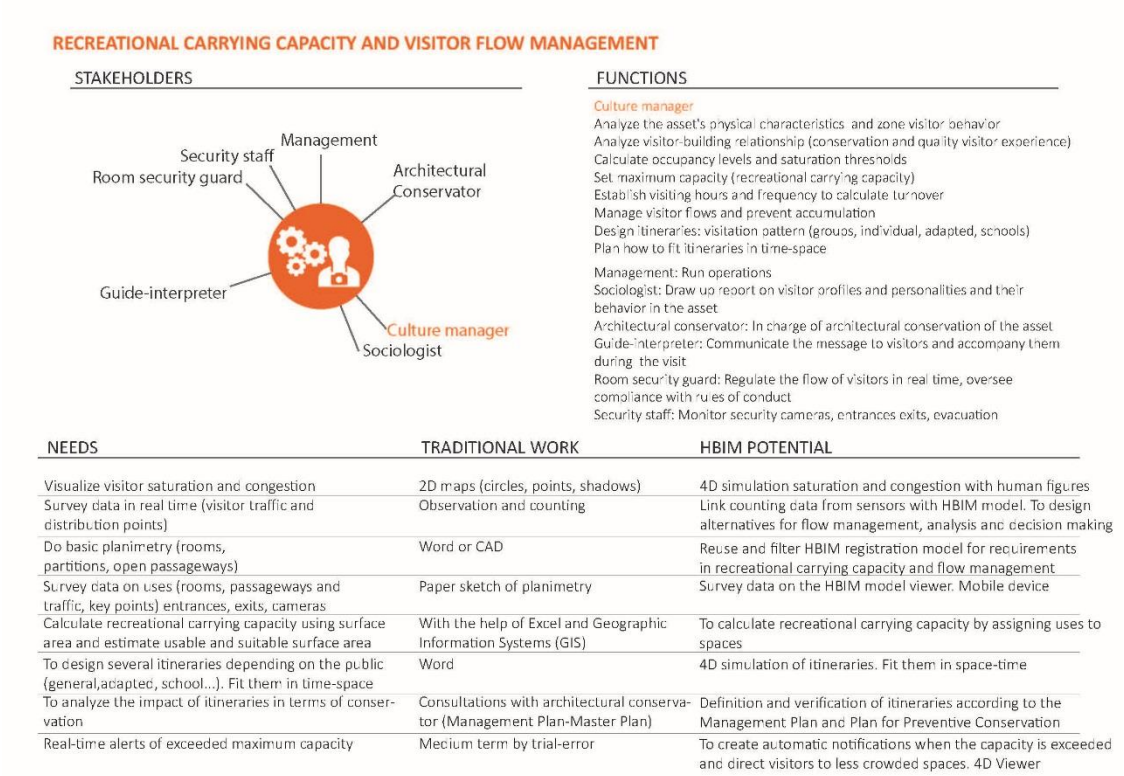
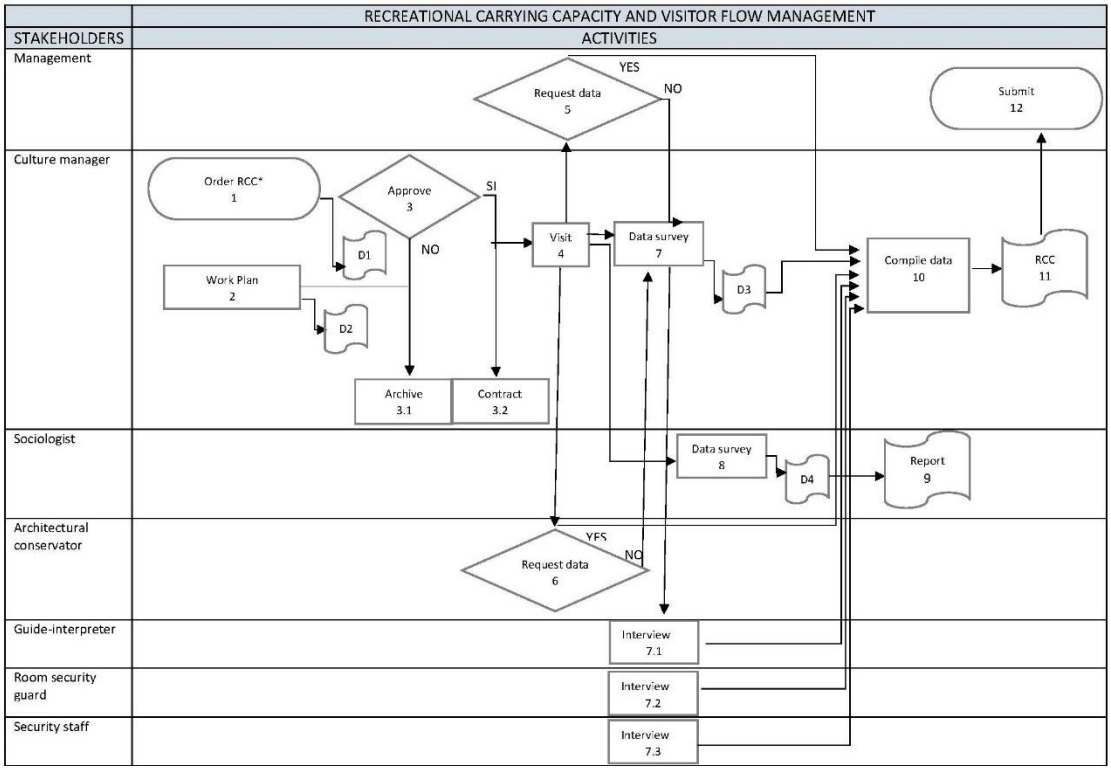


Figure 5. HBIM Potential for Recreational Carrying Capacity and Visitor Flow Management

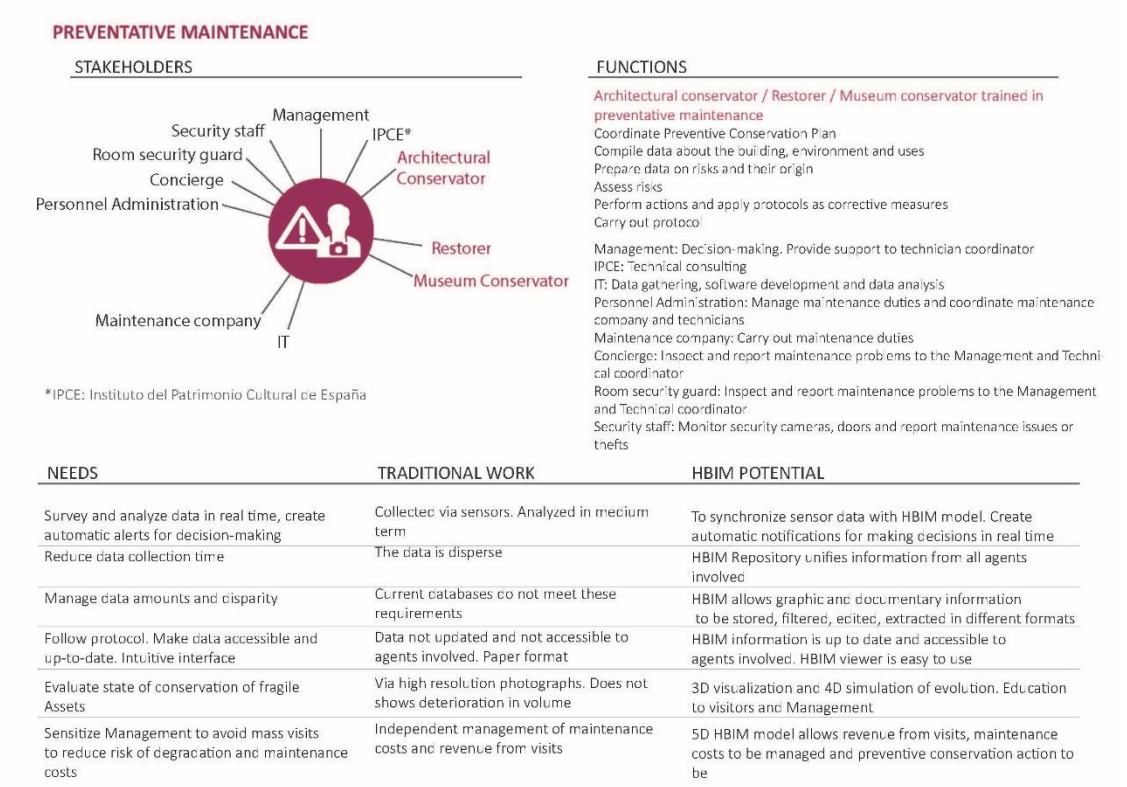


*RCC= recreational carrying capacity

Figure 6. Flow chart of recreational carrying capacity and visitor flow management

From the bibliographic analysis and the answers of the interviews with experts about the preventative maintenance (Figure 7), it is necessary to point out that in BIM, preventative maintenance of heritage buildings is assimilated into the facility management (FM) of the existing buildings (Hegazy, 2017). There are many references to BIM as applied to facility management and maintenance of existing buildings (Hosseini *et al.* 2018), though it must be said that a specific HBIM protocol for preventative maintenance of heritage buildings has not yet been developed. Hawas and Marzouk (2017) state that the information contained in the HBIM models aides preventive maintenance management in achieving enhanced conservation of heritage sites. Phase 7 of the HBIM cyclic diagram of the Council on Training in Architectural Conservation (2016) and by Jordan *et al*. (2018) includes preventative maintenance. Baik and Boehm (2017) suggest linking HBIM models with security and fire systems to manage heritage maintenance. On its part, the Santa María la Real Foundation (2017) has developed a Monitoring Heritage System (MHS) for intelligently managing preventative maintenance. The system makes it possible to monitor the state of the asset, create alerts and correct alterations automatically.

The flow chart corresponding to preventative maintenance is shown in Figure 8.



NEEDS	TRADITIONAL WORK	HBIM POTENTIAL
Survey and analyze data in real time, create automatic alerts for decision-making	Collected via sensors. Analyzed in medium term	To synchronize sensor data with HBIM model. Create automatic notifications for making decisions in real time
Reduce data collection time	The data is disperse	HBIM Repository unifies information from all agents involved
Manage data amounts and disparity	Current databases do not meet these requirements	HBIM allows graphic and documentary information to be stored, filtered, edited, extracted in different formats
Follow protocol. Make data accessible and up-to-date. Intuitive interface	Data not updated and not accessible to agents involved. Paper format	HBIM information is up to date and accessible to agents involved. HBIM viewer is easy to use
Evaluate state of conservation of fragile Assets	Via high resolution photographs. Does not shows deterioration in volume	3D visualization and 4D simulation of evolution. Education to visitors and Management
Sensitize Management to avoid mass visits to reduce risk of degradation and maintenance costs	Independent management of maintenance costs and revenue from visits	5D HBIM model allows revenue from visits, maintenance costs to be managed and preventive conservation action to be

Figure 7. HBIM potential for preventative maintenance

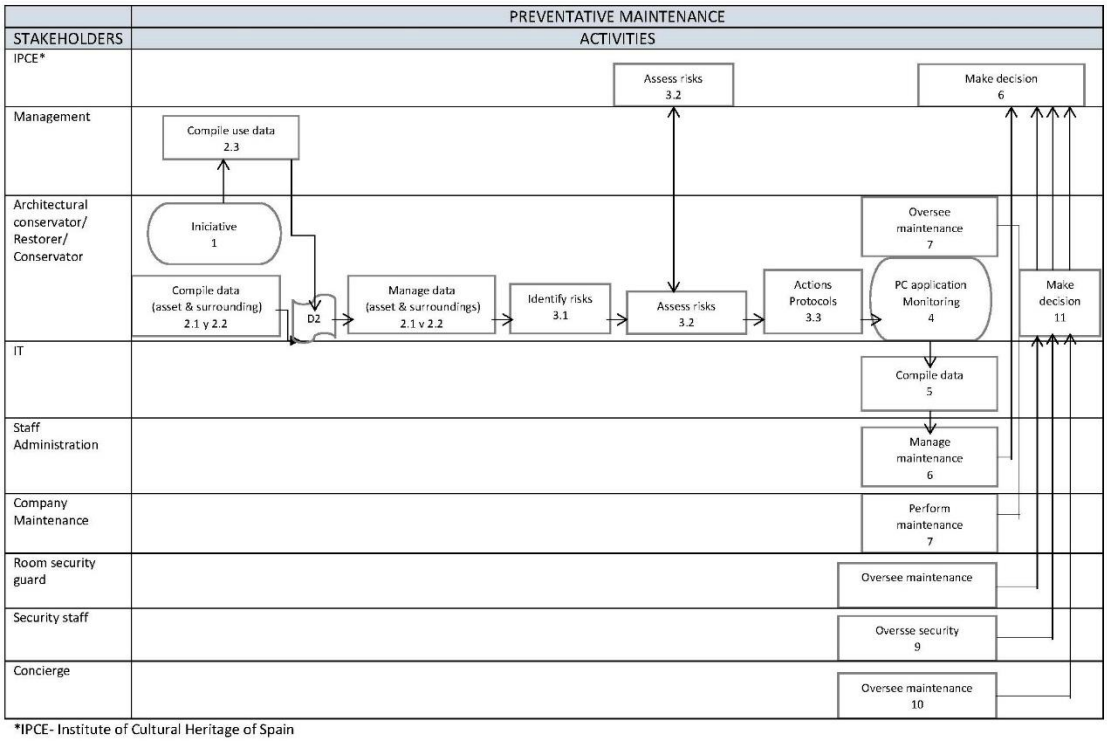


Figure 8. Flow chart for the preventative maintenance Plan

As far as issues of intellectual and emotional access to heritage and HBIM, a review of the scientific literature and interviews with experts was also conducted, in addition to an analysis of the documentation. Among the scientific work, it must be mentioned that Counsell and Taylor (2017) states that all agents involved in heritage building management must complement the HBIM models with semantic information to aide in the understanding of the value and significance of the assets. Counsell and Nagy (2017) define the primary interpretation as the first analysis of the heritage building performed by technical agents. The secondary interpretation filters the first technical analysis into an easy-to-understand narrative that will seek to pass on the historical, architectural, social and cultural importance of the site to the public. The graphical and semantic information about the significance and value contained in the HBIM models are therefore potentially useful for developing heritage interpretation programs.

The results provide information as to the functions of the main stakeholders involved in the issue, their relationship with other stakeholders, and the needs and potential of HBIM for these functions were identified (Figure 9) and the corresponding flow chart of traditional processes related to the interpretation program was developed (Figure 10).

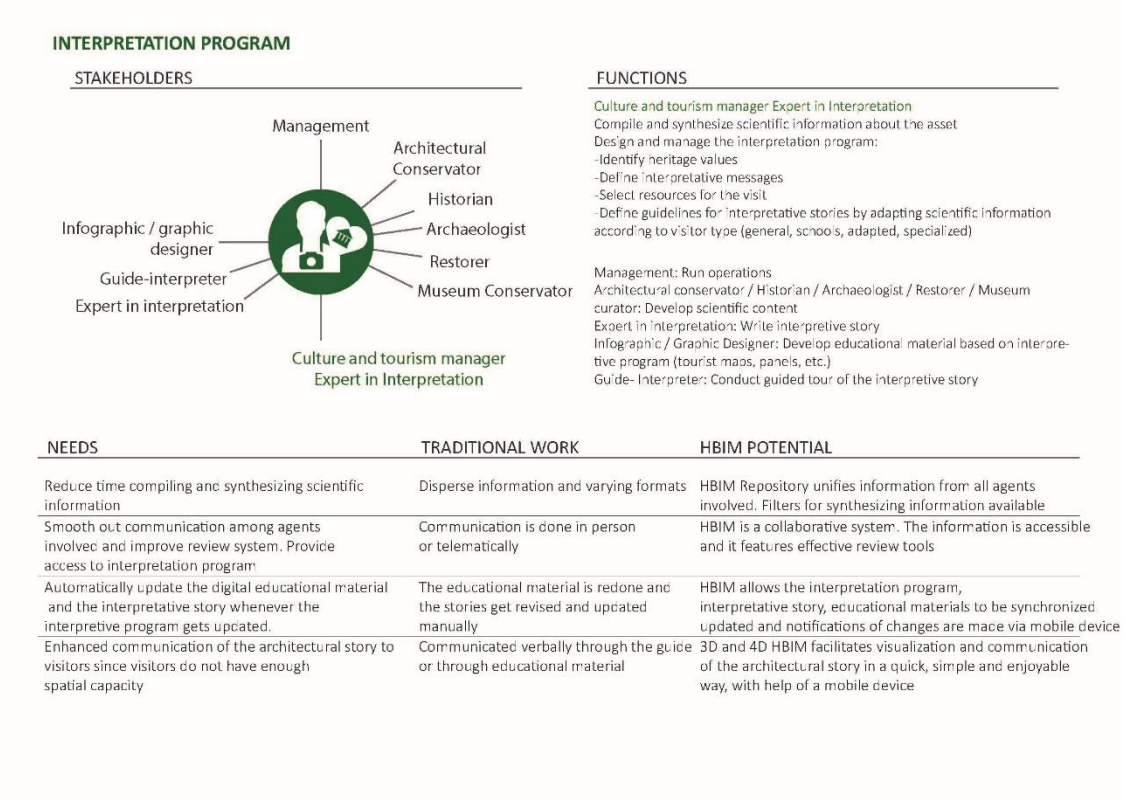


Figure 9. Potential of HBIM for developing the Interpretation Program

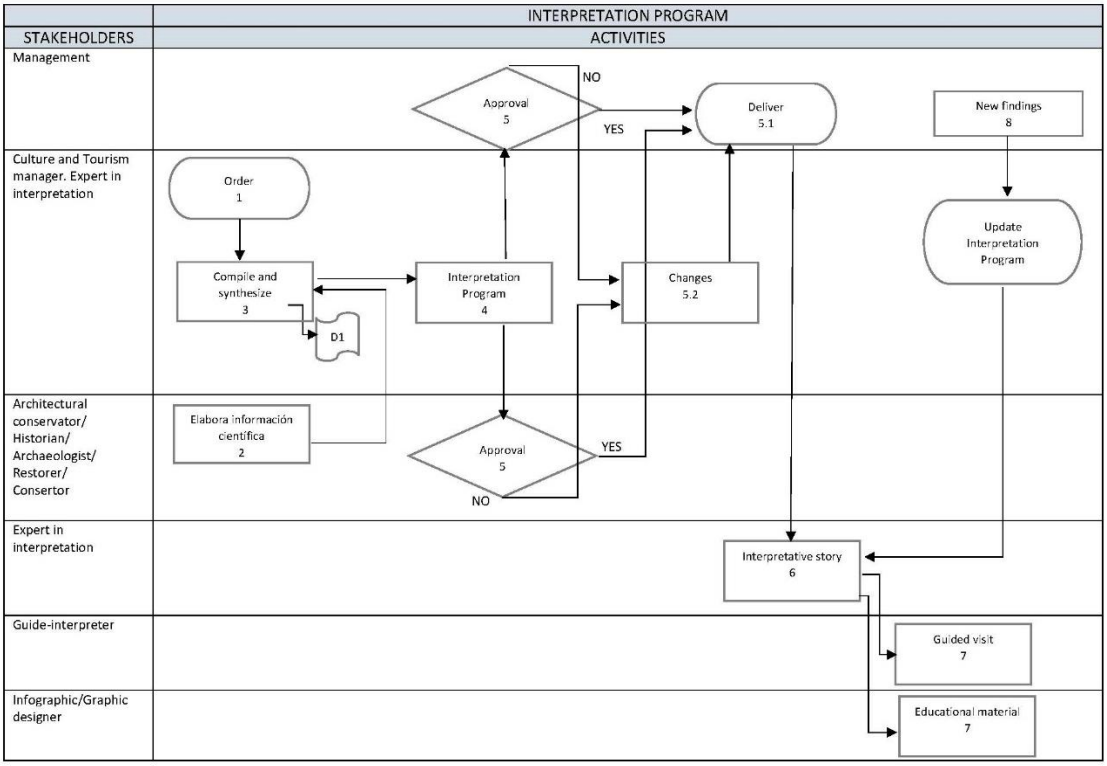
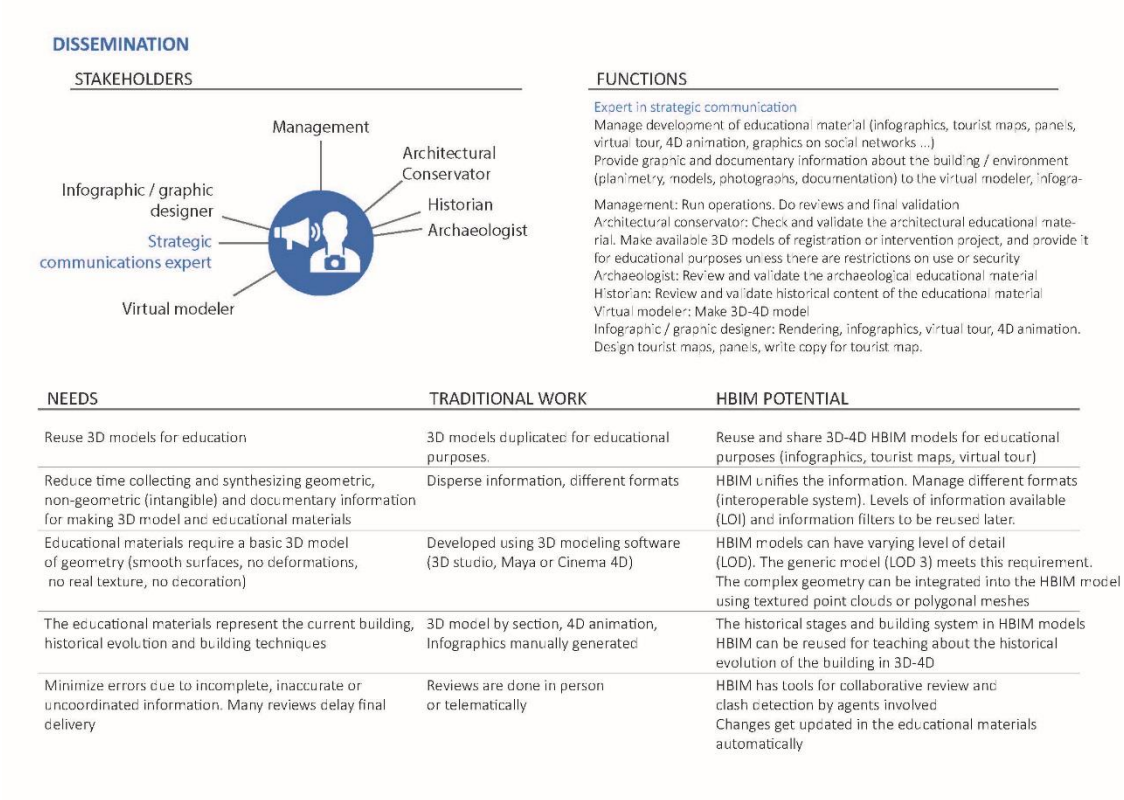


Figure 10. Flow chart of the interpretation program

Finally, it should be mentioned that several studies focus on the use of HBIM for heritage education. Brumana *et al.* [4] have used the BIM system to pass on the history of built heritage

for tourism-related ends. Barazzetti *et al.* (2016), Cos-Gayón *et al.* (2016) and Hilfert *et al.* (2016) reused HBIM models for virtual visits. Baik and Boehm (2017) believe HBIM provides many benefits for understanding heritage buildings, learning about materials and building techniques. In this way, it can be seen that producing infographic material using HBIM can be a perfect complement for passing architectural knowledge on to visitors as support for the verbal story provided by the guide-interpreter.

The results on the functions of the main stakeholders involved in teaching about the needs and potential of HBIM for these functions are presented in Figure 11 and the corresponding flowchart has been developed (Figure 12).



NEEDS	TRADITIONAL WORK	HBIM POTENTIAL
Reuse 3D models for education	3D models duplicated for educational purposes.	Reuse and share 3D-4D HBIM models for educational purposes (infographics, tourist maps, virtual tour)
Reduce time collecting and synthesizing geometric, non-geometric (intangible) and documentary information for making 3D model and educational materials	Disperse information, different formats	HBIM unifies the information. Manage different formats (interoperable system). Levels of information available (LOI) and information filters to be reused later.
Educational materials require a basic 3D model of geometry (smooth surfaces, no deformations, no real texture, no decoration)	Developed using 3D moceling software (3D studio, Maya or Cinema 4D)	HBIM models can have varying level of detail (LOD). The generic model (LOD 3) meets this requirement. The complex geometry can be integrated into the HBIM model using textured point clouds or polygonal meshes
The educational materials represent the current building, historical evolution and building techniques	3D model by section, 4D animation, Infographics manually generated	The historical stages and building system in HBIM models HBIM can be reused for teaching about the historical evolution of the building in 3D-4D
Minimize errors due to incomplete, inaccurate or uncoordinated information. Many reviews delay final delivery	Reviews are done in person or telematically	HBIM has tools for collaborative review and clash detection by agents involved Changes get updated in the educational materials automatically

Figure 11. Potential of HBIM for education

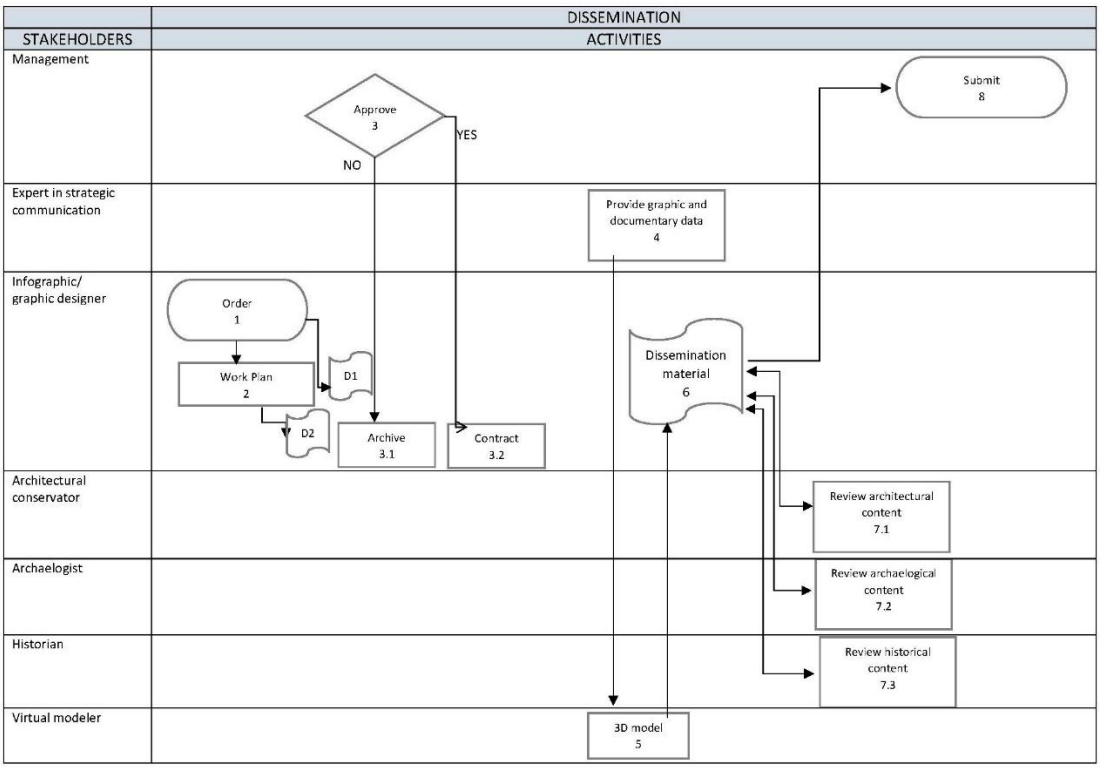


Figure 12. Flowchart for dissemination

4. Discussion and Conclusions

The analysis carried out in this study has made it possible to identify HBIM's potential for improving the effectiveness of public use management with regard to the stakeholders involved, the functions they perform, how they interact with each other, and current needs. Certain limitations have also been identified.

The review of the literature has shown that HBIM can greatly enhance the conservation of architectural heritage throughout its life cycle (Garagnani *et al.*, 2013), especially for registration, maintenance and dissemination. Public use management could benefit from the new BIM environment to improve overall efficiency in heritage conservation (Simon, 2006) since the main problem in designing information management systems, as this author states, does not lie in providing it with more data, but rather in intelligently filtering out the information necessary for decision making. BIM incorporates data into the model that can be used for effective information management throughout the life cycle (Cabinet Office, 2015). However, at this time, the information in HBIM models is not filtered or managed intelligently for public use management.

For planning and managing heritage tourism, the data must be kept up to date for proper decision-making purposes; however, the results of the interviews with the expert agents show that decision making in public use management of heritage is currently done with no up-to-date data nor access to all the necessary information.

As a system for storing, filtering and sharing up-to-date graphic and semantic information of the asset among all stakeholders in the management, and given its 3D, 4D (time) and 5D (costs) visualization capabilities, HBIM is a highly advantageous way of managing visitors' physical, intellectual and emotional access.

The major contribution of this study has been to further the work first introduced by Jordán *et al.* (2018) and to explore HBIM's potential in others that are equally significant to public use management.

The most relevant potential uses of HBIM for the carrying capacity and visitor flow management have been determined to be:

1. To visualize in 4D visitor saturation points and congestion via human figures.
2. To acquire visitor distribution data in real time with a sensor for counting visitors and link it to the HBIM model. To design alternatives for managing visitor flow based on real data, to analyze them virtually and make decisions.
3. To reuse and filter graphic and documentary information of the HBIM model registry for the specific requirements of recreational carrying capacity and visitor flow management.
4. To gather data on how rooms are used, transit spaces and traffic at key points, as well as the entrances, exits and rooms via a viewer of the HBIM model on a mobile device.
5. To calculate the recreational carrying capacity by assigning uses to spaces.
6. To design various itineraries according to visitor type (general, adapted, school, specialized, etc.) and simulate in 4D how they might fit together in space and time for decision making.
7. To generate automatic alarms when the room capacity is exceeded and direct visitors to less crowded spaces.

For preventative maintenance, the following HBIM functions have been identified:

1. To acquire data from sensors, synchronize them in real time using the HBIM model, and generate automatic alarms to make decisions in real time.
2. To gather the information from the agents involved together into a single HBIM repository, to reduce data collection time.
3. To manage (enter, filter, edit and extract) the variety of data necessary for preventative maintenance.
4. To monitor the preventative maintenance protocols, access updated information from all the agents involved in one easy-to-use HBIM viewer.
5. To visualize in 3D and to simulate in 4D the changes in the state of conservation of fragile assets. To use it as educational material for visitors and staff managing the asset.
6. To plan out more sustainable conservation in a 5D HBIM model. To draw links between the income from visits and the maintenance costs involved, with the budgets available for conservation.

Additionally, the potential of HBIM identified with regard to interpretation are:

1. To reduce the time compiling and synthesizing scientific information, filtering information from the agents involved for the interpretation program.
2. To smooth communication among the agents involved and the review system by using specific HBIM tools for clash detection. To provide all the technicians involved with access to the interpretation program.
3. To automatically update changes to the interpretation program and the educational infographic material and create alerts as to these changes via mobile devices.
4. To create graphic 3D and 4D HBIM models for complementing educational activities, thus improving the interpretation of architectural value in a quick, simple, and enjoyable way, with the help of mobile devices.

Regarding graphically-represented educational media, HBIM makes it possible:

1. To reuse the 3D-4D HBIM recording models for educational purposes (infographics, tourist maps, virtual tour).
2. To reduce the time for compiling and synthesizing graphic and documentary information for making the 3D model and educational materials through levels of information (LOI) and filters.
3. To use the basic generic model (LOD 3) to develop educational materials. Complex geometry can be integrated into the HBIM model using textured point clouds or polygonal meshes.
4. To reuse the building phases from HBIM models to represent the building's historical evolution (3D views and 4D animations) and the building techniques used.
5. To prevent errors and minimize revisions in educational materials by using clash detection tools. To automatically update changes in educational materials.

The limitations pointed out by the interviewed experts are a lack of essential infrastructure, lack of BIM training among asset management and administration staff, and the need for an intuitive, highly visual interface for non-technical personnel and volunteers involved in public heritage visits.

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