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Behavioural Simulation for Built Heritage Use Planning

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This paper presents a system for simulating human behaviour in built heritage artefacts aimed at supporting the decision-making processes for their possible re-use.Its goal is to predict the mutual influence between the occupancy phenomena and the architectural heritage environment, in order to optimise the balance between efficiency requirements of spaces and preservation needs of the heritage artefact. The proposed system is based on the integration of a BIM environment with a game engine that allows the modelling of the built environment and the simulation of its use phenomena at the same time. A central role in the systems is played by the distribution of Artificial Intelligence among Virtual Users, process entities (the activities) and the building components, ensuring the coherent representation of the use processes and the direct measurement of their impact on the artefact.

Keywords: *Built Heritage, Human Behaviour Simulation, Agent-Based Modelling, BIM*

RATIONALE

In the continuous evolution of cities, identification, conservation, and adaptation of built heritage are relevant aspects of their cultural and urban development, both in the case of acknowledged historical towns and more recent urban areas. Especially in Europe, a long debate arose about the possibility of re-use to give new functions to heritage buildings. However, despite the necessity and the opportunity of giving new life to these environments, several problems arise in terms of preservation and actual capabilities of hosting new functions, users and activities. As a matter of fact, the goals of preserving architectural heritage and upgrading and re-using those spaces seem to be often in conflict. This occurs whenever the intervention process aims at improving technical performances, forcing new uses into an existing building without taking into account the issues of compatibility. In this context, specificity and uniqueness of heritage artefacts have highlighted the limits of current approaches, mainly based on the use of too general norms and regulations. As a result, at present, it is quite difficult for designers to conceive a design that effectively balances preservation and re-use instances.Today, digital models play a key role in making heritage buildings part of the contemporary urban life by encouraging the convergence of past and present knowledge to facilitate their interpretation, allowing the virtual reconstruction of their configurations over time as well as supporting the prefiguration of their future (Kalay 2008). Despite the introduction of several virtual simulation tools in built heritage, their main applications in this field are for communication purposes (Serdar 2015; Boeykens 2011). Simulations (being often just animations) have been developed and introduced in museums and archaeological sites to visualise and communicate past uses of the artefacts, sometimes with the possibility of interaction between the users and the virtual non-player characters, in order to enhance their learning attitude (Affleck 2005).Nevertheless, the important task of predicting and evaluating the capabilities of a built heritage artefact hosting new users and uses is still unsupported and completely left to designers' expertise and imagination.To overcome this lack, the objective of the research presented in this paper is the development of a simulation model for the prediction of occupancy phenomena related to the re-use of built heritage, taking into account both the efficiency of the assigned new functions and their possible impacts on the artefact and its preservation.The proposed model has been applied to different case studies concerning architectural heritage planning, each of them encompassing its own features, preservation requirements and intended uses. As an example, the model was tested in supporting decisions about the different use scenarios of a renaissance cloister in Rome (currently part of Sapienza University Campus) in order to improve its efficiency and usability as well as reduce mutual interference in activities besides the risk of damages and decay.

STATE OF THE ART

Virtual prediction of built environment occupancy is a quite popular topic in the CAAD world, even if it is mainly focused on behavioural simulation in not-yet-built environments. A big shift in this field was the spreading of the Agent-Based Modelling (ABM) paradigm in the early 90s. Since then, much research has been carried on its application to architectural design processes, in particular for the prediction of people movement in special typologies of buildings including airports (Krijnen 2009), shopping malls (Zhu 2016), railway stations (Lee 2001), and urban spaces (Yan 2004; Batty 2001). These applications rely on ABM traditional principles, considering each person as an autonomous entity provided with a limited set of behavioural rules which control and generate its behaviour, according to specific objectives and to the surrounding context (environment and other agents) (Macal 2007). While this approach has already shown excellent results in simulating simple autonomous behaviours - such as spatial mobility- some limits emerged in their application to more complex systems of actions, activities and cooperation among people which are the cardinal elements of a building use process. More recently, some research has focused on the simulation of systems of activities within buildings rather than just movement prediction. Wurzer (2010) proposed an agent-based system for early stage spatial planning while the ISSUU system, introduced by Tabak (2004), relies on an automatic, time-based organisation of activities and on their subsequent simulation. Integrating ABM and process-driven approaches, Simeone (2012 and 2013) and Schaumann (2015) presented another methodology - defined as Event-Based Modelling - that relies on AI distribution not only for virtual users but also for process entities - the Events - in order to control and coordinate the performing of activities in a coherent and structured process. The objective of all these approaches was to support design decision about not-yet-built environments and to predict and evaluate the impact of a proposed design on activities and operations of the intended users of the building. In addition to the operational dimensions, these methodologies can also provide useful feedbacks on other use-related phenomena, such as energy consumption and environmental control.While in the field of new buildings there is an extended literature on this topic, only some research has focused on ABM for heritage buildings, which was mainly limited to simulation of fire egress and similar safety issues. At the date of this paper, a simulation model to predict the mutual influence between the intended re-use processes and the built heritage artefact itself, and to support the assessment of the impacts on both the users (and their operational needs) and on the artefact preservation, is still missing.

SIMULATING USERS' BEHAVIOUR IN BUILT HERITAGE ENVIRONMENTS

Capitalising previous research on event-based modelling (Simeone et al., 2012, 2013; Schaumann et al., 2015), the proposed model for behavioural simulation for built heritage relies on simulating in a virtual environment the use narratives constructed through a combination of actors, activities and built environment entities. Differently from pure Agent-Based models, in which each Virtual User (V-User) performs an autonomous behaviour, in the event-based modelling this autonomy is reduced and partially influenced by process AI entities, the events, that control cooperative performing of activities and, at a higher level, the coherence of the entire simulated use process and of its adherence to real world phenomena. This methodology is particularly effective in prediction of use phenomena in built heritage artefacts since it suits the articulation and complexity of heritage buildings re-use, generated by users' behaviours, movements and activities. If compared to event-based modelling and other simulation paradigms, an element of novelty, peculiar for the context of architectural heritage, is the focus not only on the environment influence on users' activities but also on the impact of re-use on the heritage artefact preservation. Therefore, the built environment has been modelled considering two different entities typologies that refer respectively to the spaces domain and the technological components articulation. While previous work on event-based modelling mainly considered the environment domain in term of spaces (Simeone, 2012, Schaumann, 2015), the inclusion of technological components allows to provide them with some behavioural rules to measure different aspects of the interaction with the intended use and users.This assumption relies on the idea of a more comprehensive model of the building and its use as a system of interacting entities, each of them made of its geometrical representation, its non-geometrical features, and its behaviour. Therefore, the simulation platform is a distributed intelligence system, where AI and computational resources are assigned to (Figure1):

- V-Users entities (as in current agent-based systems);
- process entities, events and scenarios (as in activity-based modelling);
- entities that are part of the built environment (similarly to cellar automata systems).

While the V-Users AI is oriented to the generation of their autonomous behaviour, the built environment entities are provided with computational capabilities in order to monitor, measure, assess and update the status of the built environment in accordance with the impacts of the V-Users behaviour. The core of this approach is the act of modelling the system building-use-users as a set of agents, rather than having a "passive" environment and V-Users acting in it. Relying on specific use scenarios developed by designers in collaboration with clients, the model is populated with V-Users and "placed" activities indicating where an activity is going to be performed. Once activated, the "placed" activities can simulate their own performing by controlling and coordinating V-Users' actions until completion . In order to guarantee the coherence of the entire simulated scenario, the system is provided with a Narrative manager which directly controls and coordinates the V-Users behaviour according to the predefined temporal structure of activities. In this way, the autonomous and sometimes arbitrary actions of the V-Users are controlled and included in a more coherent simulation of the use of the built heritage artefact. While, in the previous works, activities entities have been modelled as abstract entities for process formalisation, in this application to built heritage, they have been provided with some physical features such as performing_position and area_of_influence. The inclusion of these two aspects enhances the phase of planning use scenarios. Architects and managers can populate the virtual built environment by placing different typologies of activities in accordance with the intended future use, while the area of influence geometry shows the areas of the environment that will be spatially influenced by the performing activities. Both are controlled by parameters and can dynamically vary during the simulation according to contextual occurrences and to the status of the surrounding environment. Each activity entity is provided with a programming script that 1) verifies the conditions that are necessary for its performing, 2) executes the set of related actions, and 3) updates the status of the different entities involved. Through this script, it is also possible to represent and manage unplanned activities: a set of rules can control the activation of these activities only when and where some conditions are satisfied during the simulation itself (Figure 2).

Smart building components for use impact assessment

Another relevant aspect of the proposed model is the choice of modelling the different components of the artefact not as static, passive entities but as "smart" elements provided with their own set of behavioural rules (see also Lee 2007). This set of rules, implemented by means of specific behavioural scripts in the game engine, do not actually control behaviour but they rather assess the variation of specific parameters related to preservation of the element. While the simulation is running, the built environment entities, equipped with AI resources similarly to the V-Users and the Activities ones, measure the effects of users' behaviour on them (and on their preservation) providing immediate feedbacks to the architect. For instance, an antique floor can "feel" the loads related to the users passing and stopping on it, or a fresco-painted wall can signal that the presence of too people nearby can cause damages. In this way, designers and clients can intervene on the configuration of the environment or on the planned use process (or both), calibrating and optimising conservation and use instances. The result is an ad hoc design solution for the artefact, that keeps into account its specificity and uniqueness. For this aspect, Building information modelling is particularly effective in this context since it allows to include in the artefact representation variables and parameters related to non-geometrical features that can be useful for the use simulation. Although decay and preservation of an artefact component are very complex aspects that embed a large system of variables, conditions and interactions with other elements and actors, simplified functions, and algorithms can be used to provide a qualitative feedback regarding the impact of intended use and of users' behaviour. The choice of considering the building components as active en-

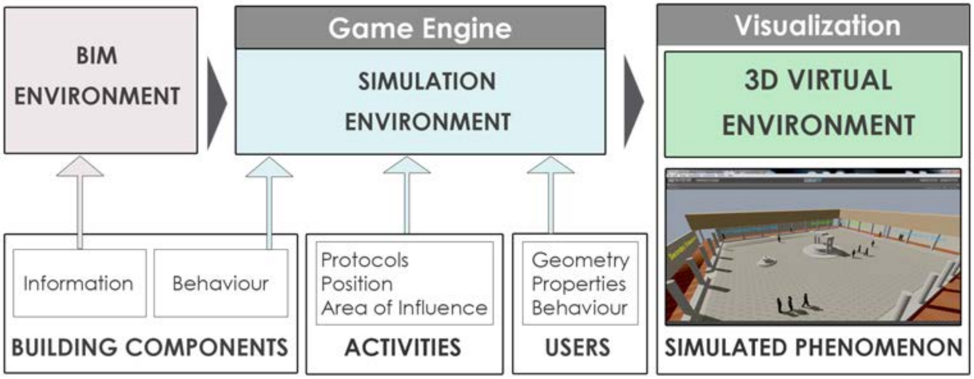


Figure 1
The conceptual framework of the proposed system: a BIM environment integrated with a Simulation platform (a game engine) to allow modelling of the heritage artefact and simulation of its intended use processes.

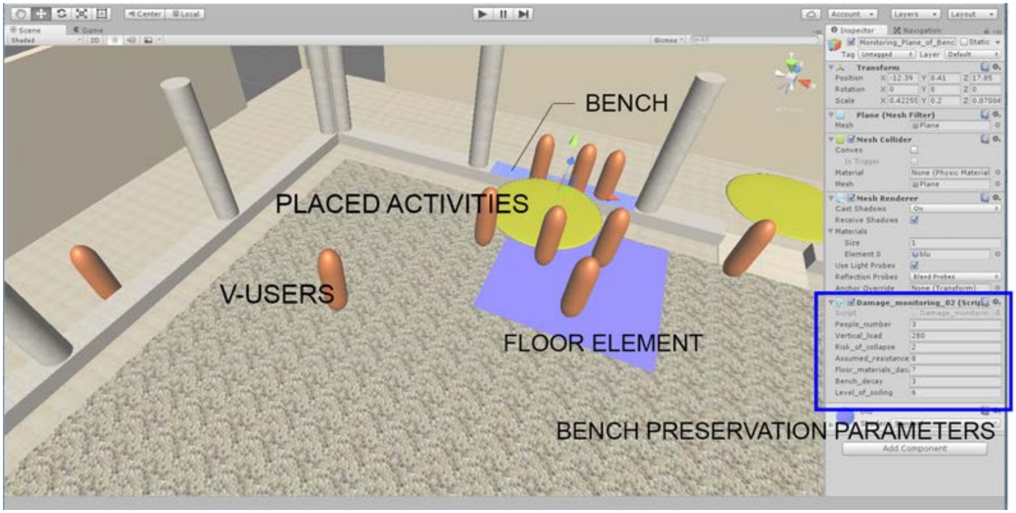


Figure 2
The application of the proposed model to the use simulation of Saint Peter Cloister (Rome, XV Century). In this picture are highlighted the main elements of the model: 1) V-Users agents (schematically represented), 2) placed activities (in charge of controlling the performing of collective and coordinated actions), 3) artefact components, provided with AI to control preservation variables.

tities with their own ability to measure the impact of use processes on their conservation, also ensure a good extensibility and flexibility of the model: by adding specific measurement rules, different aspects of artefact preservation can be assessed and considered during the simulation.

IMPLEMENTATION AND CASE STUDY

From the implementation perspective, the platform has been developed using the game engine (Unity 3D v.5) where agents' behavioural rules, activities-performing rules, and narrative manager protocols are scripted in C. The artefact and its different elements can be modelled using a BIM software (in our experiments we used Autodesk Revit 2016) and later exported to the game engine platform, in which the entities are enriched with behavioural scripts in accordance with their typology and the preservation aspects to consider. In our experiments, the process of exporting the geometry of elements was performed through the Unity for Autodesk Revit 1.2 application, recently distributed by Autodesk.The model has been applied to the simulation of different use scenarios of the 'Cloister of San Pietro in Vincoli' (designed in the XV Century by Sangallo) originally part of San Pietro Church and now embedded in the Engineering Faculty of Sapienza University of Rome. This environment currently hosts different activities and users, with several variations during the day and in case of special events: students and faculty members use it to reach the classrooms located on two of its sides and as a resting place during breaks; tourists visit it since it is well known in the history of the city of Rome; different configurations are created by means of mobile partitions for exhibitions or for conferences; during the summer, the cloister even hosts some movie events and concerts. All these activities and use destinations rise two problems: the mutual interference and the risk regarding Architectural Heritage artefact and its main components such as the columns or the classical central font. By simulating these situations and, if relevant, their possible combinations, designers and facility managers are now able to test different spatial configurations and use protocols and policies, assessing for each proposal pros and cons in terms of efficiency and built heritage preservation (Figure 3, 4).

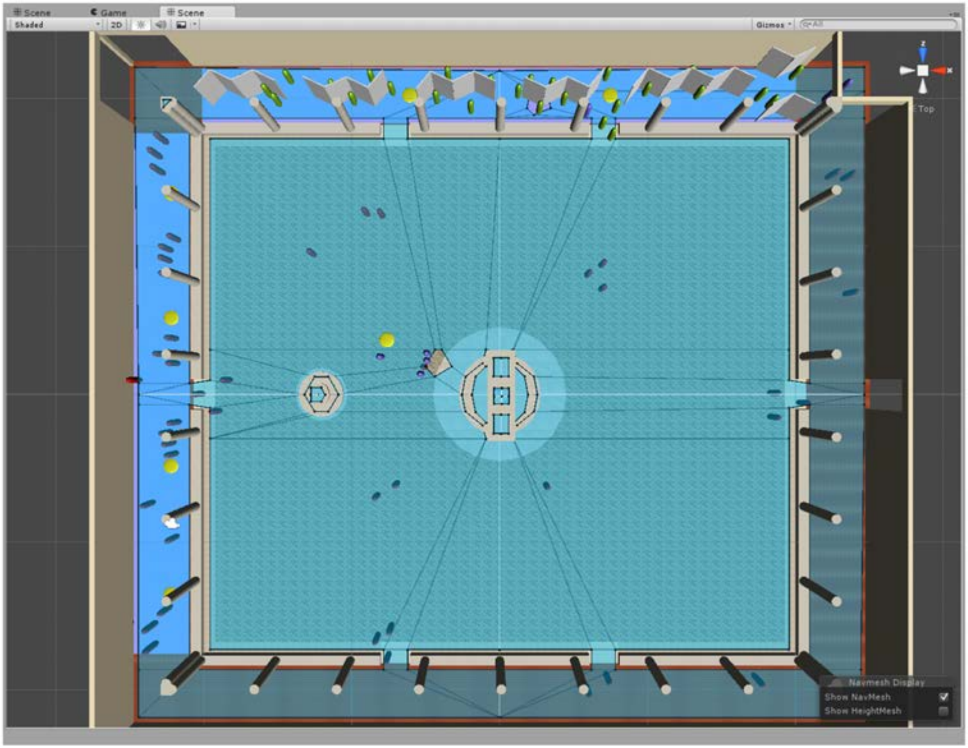
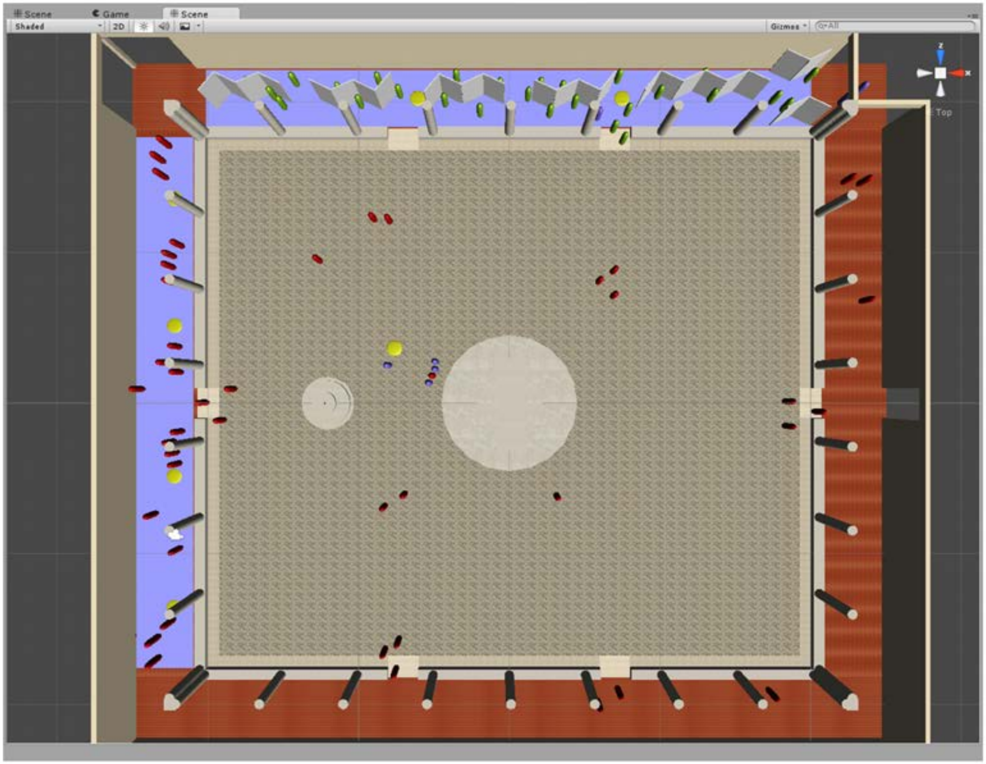


Figure 3
The walkability map computed through the navigation panel of Unity 3D.

CONCLUSIONS

This paper presents the development of a modelling and simulation approach for prediction of possible re-use phenomena of built heritage artefacts as well as their impact on preservation. In the complex decision-making process regarding interventions on built heritage in order to give it new functions and use, the proposed model allows balancing preservation and use instances, providing a way to optimise the design. In fact, it allows to virtually predict how the building will appear when finally occupied and in use and, at the same time, to verify the impact of the intended use phenomena on its different components. Through this prediction and assessment phase, architects and all the other actors involved in the process, including clients, will be able to test different design solutions and to conceive different use scenarios for the building, assessing for each proposal the actual impacts on the heritage artefact. If compared with the complexity of human behaviour and interaction with a built environment, especially if considering architectural heritage artefact, the model has necessarily to rely on some simplified assumptions that make the large amount of variables and variations of such phenomena more manageable. Since the proposed model is currently conceived to support early planning phases, where qualitative predictions are more effective than quan-

Figure 4
The simulation of an art exposition in the Sapienza Cloister during normal functioning of the faculty (developed in the Unity 3D environment.



titative ones, the simplified assumptions still ensure a good reliability of the simulation and useful feedbacks to the different actors involved in the decision-making process. Future work within this research scope will focus on additional testing and calibration of the model, in order to improve adherence to real phenomena and more accurate estimation of users' behaviour impact on the built heritage artefact.

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