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Multi-scale urban data models for early-stage suitability assessment of energy conservation measures in historic urban areas

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ABSTRACT

The demand for improving the energy performance of buildings located in the historic districts of cities is as high as the current demand in other city districts. The need to reduce energy consumption and improve the comfort of inhabitants is compounded by the need to preserve an environment of heritage value. The selection of rehabilitation strategies at urban scale offers significant benefits, but makes the process long and costly. Therefore, methods or tools are necessary to establish a rapid assessment that facilitates strategic decision making and a deeper analysis of a reduced number of alternatives.

This paper describes a method that supports decision making regarding the suitability of Energy Conservation Measures (ECMs) in historic districts at early stages. The method considers the improvement of the energy performance of buildings as a positive impact, balanced with the negative impacts that the implementation of ECMs could produce. A CityGML-based urban model allows the automation of a multi-scale assessment for different ECMs and provides possible global energy demand reductions. This method, combined with an economic evaluation, can be used by decision makers for large-scale energy retrofitting. The applicability of the method is demonstrated through implementation in the historic city of Santiago de Compostela.

1. Introduction

The interest in improving the energy efficiency and thermal comfort of historic built environments arises from a double demand: the sociocultural need to preserve historic cities and the environmental need to reduce the global energy demand of buildings. The cultural heritage of a city has proven to be an important feature for the wellbeing of citizens and historic buildings are highly appreciated [1,2], but city dwellers frequently choose more modern buildings since they are perceived as more comfortable than historic ones.

Buildings that are not used are rarely conserved, thus making the abandonment of historic cities a major urban conservation problem. The Council of Europe, in the Amsterdam Declaration of 1975, promoted the concept of integrated conservation establishing the improvement of the liveability and quality of life of their citizens as one of the main objectives of urban conservation [3]. There is a close relation between liveability and energy efficiency. The objective of Energy Conservation Measures (ECM) is to provide suitable environmental conditions to the inhabitants and minimize the used energy [4]. The improvement of the energy efficiency of historic districts in general and their housing stock in particular reduces the energy demand required to reach comfort standards, enhancing the quality of life of their habitants in an affordable way.

Energy upgrading of historic buildings is not only a cultural issue but also important in terms of global environmental objectives in Europe since over 40% of the European housing stock was built before 1960 [5]. The Housing Statistics in the EU show that 24% of residential buildings of the European building stock are pre 1945 [6] and that a significant percentage have some kind of heritage significance [7], requiring specific solutions to conserve and promote these values.

Recent literature reviews regarding energy efficiency and thermal comfort in historic buildings highlight the importance of carefully balancing the improvement of energy efficiency measures and the integrity and authenticity inherent to historic buildings [8]. As recent research concludes, “there is a lack of a specific protocols aimed at providing well-balanced solutions for the energy efficiency improvement in historic and historical buildings” [9]. This lack is even more noticeable if we address the problem at the urban scale.

Studies at the urban scale can consume large amounts of energy and money due to the amount of information that is required, often as a result of field work. 3D models are an increasingly ac-

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Nomenclature

A	Applicability
BNHIA	Number of buildings with a negative HIA
NB	Number of buildings
EF	Economic Feasibility of the ECM
ES	Energy Saving of the ECM for that building
CE	Cost of the ECM for that building

cepted solution for storing and displaying information at both the building and urban scales. They offer the same benefits as 2D GIS but provide further functionality through the third dimension [10]. This paper describes an early-stage suitability assessment (ESSA) method of ECM in urban historic areas supported by 3D models. The method balances the benefits of a given ECM with its negative impact on heritage significance. The applicability and economic feasibility of ECMs at the urban scale complement the assessments. The method is tested in Santiago de Compostela (Spain).

The rest of this paper is structured as follows: Section 2 reviews the related work; Section 3 describes the ESSA method and the multiscale data model, which is a data model where multiple scales coexist (from building components to the city), that supports its automation and the decision making at different levels (district level and building level); Section 4 explains the implementation in the case of Santiago the Compostela; and, finally, the conclusions and future work section closes the paper.

2. Related work

The Heritage Impact Assessment (HIA), which originated in the framework of environmental impact assessments, is a tool to assess the acceptability of impacts caused by new interventions on cultural heritage assets. In this framework, the evaluation of the overall impact of an intervention is a function of the magnitude of the heritage value and the magnitude of the changes produced by the intervention. The International Council on Monuments and Sites (ICOMOS) has developed guidance to implement the HIA specifically for World Heritage properties [11] . In this method, the positive and negative effects of new interventions are systematically assessed in contrast to the heritage significance values. This approach has been recently applied to urban development projects not only to reduce its negative potential impacts on cultural heritage but also to balance them with socio-cultural and economic benefits as beneficial impacts [12].

Industrialisation brought mechanical systems to modern architecture, decisively changing the relationship between our cities and the environment. Preindustrial architecture was built in a time when the comfort could not rely on mechanical systems. This traditional architecture takes into account the constraints that the climate and the local material impose [13] and consequently has an *instinctive care* to the whole life cycle of building materials [14]. Pre-industrial buildings are different from an energy behaviour perspective to modern ones, and they are not necessarily worse [15]. The way that historic buildings address environmental conditions to provide comfort conditions to their inhabitants must be considered part of their cultural value and technical heritage. Moreover, affordable comfort makes easier to keep the historic buildings inhabited thus facilitating their conservation. Therefore, improving energy performance can be considered to have a positive impact on the heritage significance of the historic buildings, as long as it is aligned with the conservation of the other components of this heritage significance. In this regard, the recently approved European Standard, EN 16,883 (Guidelines for Improving the Energy Performance of Historic Buildings) provides a procedure for the planning of ECMs taking into account the impact in the preservation of the cultural values at building level.

Suitability of Energy Conservation Measures can be evaluated by balancing the positive impact to the preservation of cultural values (improvement of the energy efficiency and thermal comfort) with their negative values (impact on the authenticity and integrity of the building elements). From the cultural point of view, historic urban areas are information-rich environments, with multi-scale heritage values that envisage from urban landscape to building elements (such as windows, walls or chimneys) where a unitary and multi-level approach is required [16]. Although the district scale is the operative scale for the implementation of ECMs [17], the spatial decision processes for their implementation has to be addressed with a multi-scalar approach [18]. The implementation of ECMs in historic urban areas may thus benefit from information management strategies and tools, such as multi-scale and semantically enriched 3D city models [19].

Ross et al. defined a 3D city model as a georeferenced digital representation of objects, structures and phenomena that correspond to a real city [20]. The same authors identified CityGML as a very powerful interchange format for official 3D city models. CityGML is a multi-scale data model format that falls between the traditional 2D GIS and Building Information Modelling (BIM) scales [21]. Covering different levels of CityGML allows the reuse of the same data in different fields of application [22], and it was designed to store semantic and 3D multi-scale geometric information, considering urban and building scales [23]. In the comparison between different 3D exchange standards made by Vandysheva et al. [24], CityGML is the most complete standard, being the only one that supports different Levels of Detail (LoDs) and one of the most complete regarding the inclusion of both semantic and geometric information. The widespread use of CityGML across Europe is another advantage [25].

In energy modelling, the heating, cooling and ventilation demands of buildings, and therefore districts, are strongly dependent of the geometry of those buildings and their construction characteristics (semantic information). Consequently, the combination of spatial analysis with thematic data structuration offers an excellent way to calculate the energy demand at the urban level [26–30], to estimate the energetic rehabilitation state of the buildings in a city [31] or to represent the energy-related key indicators of buildings and neighbourhoods within 3D building models [32,33]. The prediction of the energy demand of urban districts can be used as basis for simulating energy refurbishment scenarios, as in Eicker et al. [34], and thus for decision making regarding energy interventions [35].

In the field of cultural heritage, the energy performance of heritage buildings has been mapped using 2D GIS [36], and 3D models have been widely used for the documentation of cultural heritage assets especially at object, building or archaeological site scales [37,38]. However, as far as we are aware, 3D models have not been used for the suitability assessment of ECM in historic environments.

3. Method for suitability assessment of energy conservation measures in historic urban areas

Our objective is to develop an early-stage suitability assessment (ESSA) method that facilitates the rapid feasibility and suitability assessment of ECM at the urban level in historic urban areas using open data or public sources. A multi-scale model based on CityGML is used to structure the information necessary for the assessment of negative and positive impacts at urban level of each ECM and their applicability.

The developed method adapts the ICOMOS guidance on Heritage Impact Assessment to be implemented with a multi-scale