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Integrated computational tools for virtual and physical automatic construction

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Abstract

Recent advances in computer tools have improved the ability to store, navigate and display large and complex three-dimensional (3D) models, a step forward in architectural and urban planning. The generation of photo-realistic models is a time-consuming task that requires significant human input, despite current developments in photogrammetry and 3D scanning technology. Though computer vision techniques operate automatically, they do not produce usable models, frequently being weak with respect to occlusion and changes in illumination, on top of operating with small sets of images. To solve these limitations, this research work uses a new biologically based system, called BioCAD, which mimics the human vision process. This novel system is specifically designed for the rapid and accurate generation of 3D computer models from existing large objects, like buildings, allowing a direct link to rapid prototyping systems. A World Heritage building was chosen as a case study to validate BioCAD.

Keywords: Architectural design; Biomimetics; Computer-aided architectural design; Historic buildings; Human vision; Rapid prototyping; Reverse design

1. Introduction

The restoration or renovation of historic buildings has become an important facet of the construction industry. In Europe, 50% of construction works are carried out on existing buildings. The Venice Charter is one of the International Charters created for the restoration and conservation of monuments and sites, regarded as a key benchmark for architectural building re-use.

The restoration or renovation of historic buildings can generate large economic benefits [1], drawn from the increased commercial value of these buildings and its surrounding areas in terms of tourism and investment, apart from other non-priced benefits associated with user satisfaction.

Architectural re-use can include renovation, restoration, conservation, repair, rehabilitation, refurbishment or alteration, all requiring a large range of professional expertise as shown in Fig. 1. In a design environment, each member of the design team usually has different viewpoints, goals and constraints that must be communicated and integrated until an optimised design solution is achieved. Communication problems are quite often particularly relevant within the design process.

The implementation of a collaborative environment requires computational tools to support the activities of redesign or reverse design for re-use.

A computer-aided architectural design (CAAD) environment plays an important role in the development of such a collaborative process, facilitating collaboration, coordination and communication among all the participants of the architectural design process [2–4]. Two different architec-

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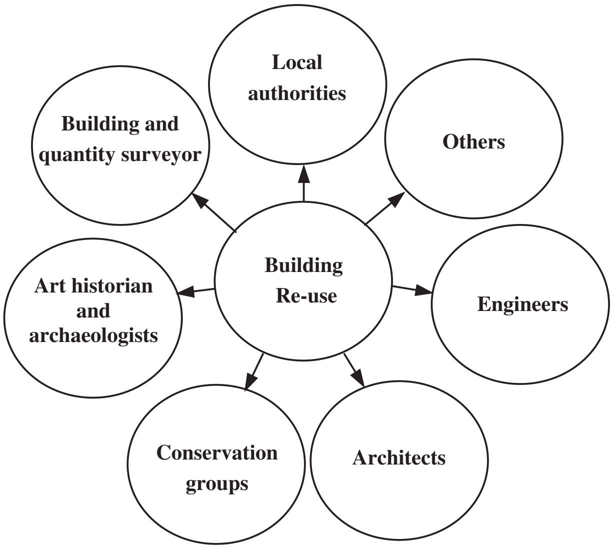

Fig. 1. Collaborative environment for building re-use.

tural design approaches can be considered [5]. A conventional design process called forward design, shown in Fig. 2, starting with a set of ideas and concepts followed by the generation of digital models, through the use of CAAD systems, which will enable to simulate and evaluate design solutions to arrive at optimised design solution. On the other hand, a non-conventional approach called reverse design starts with an existing building, from which designers must capture the geometric shape and other relevant properties through a digitisation process, to generate the correspondent digital model. Once the computer representation of the existing building is obtained, the same steps of the traditional design process are followed until an optimised architectural re-use or preservation is achieved (Fig. 2).

Distinct CAAD tools have been developed to further support the architectural design process [6–8], like Autodesk Revit Building [9], Autodesk Architectural Desktop [10], Bentley Architecture [11] and ArchiCad [12]. Recent advances in CAAD systems for advanced architectural applications and the generalisation of the use of the Internet have completely changed the way designers work. Several cases report the successful use of computers and advanced CAAD tools.

The fabrication model and drawings of Gehry's Guggenheim Museum in Bilbao were made using the software *Catia*, an aerospace and automotive CAD tool. Gehry used the most advanced computer-aided technologies of that time to bridge the gap between design and building [13–15]. Renzo Piano's Tjibaou Cultural Centre at New Caledonia was also designed and optimised in a virtual environment [16]. Piano's work on Kanzai airport was the first attempt to use computational fluid dynamics software to optimise the shape of a building [17].

Another example of reverse design is the work carried out by a research group from Stanford University that digitised and modelled seven Michelangelo's sculptures and other artefacts, including the parts of the Forma Urbis Romae [18]. The Italian National Council at Pisa developed acquisition and processing systems dedicated to heritage artefacts, while a research group from Tokyo University built shape and appearance models of a Great Budha bronze at Kamakura [19]. The digital modelling of the Saint-Pierre Cathedral in Beauvais, France, is other interesting work of historic sites' modelling [20]. The Bet Giorgis (St. George's Church), a rock-hew church in Ethiopia considered by the UNESCO as a World Heritage site, was digitally modelled by a team integrating persons from the Swiss Federal Institute of Technology, the University of Melbourne and the University of Cape Town [21]. A visualisation software named *Disp3D*, employing a view-dependent texture mapping procedure, has been used for the 3D model rendering.

All these interesting projects focus on 3D reconstruction techniques, though they do not allow the integration with rapid prototyping (RP) systems, which will enable the

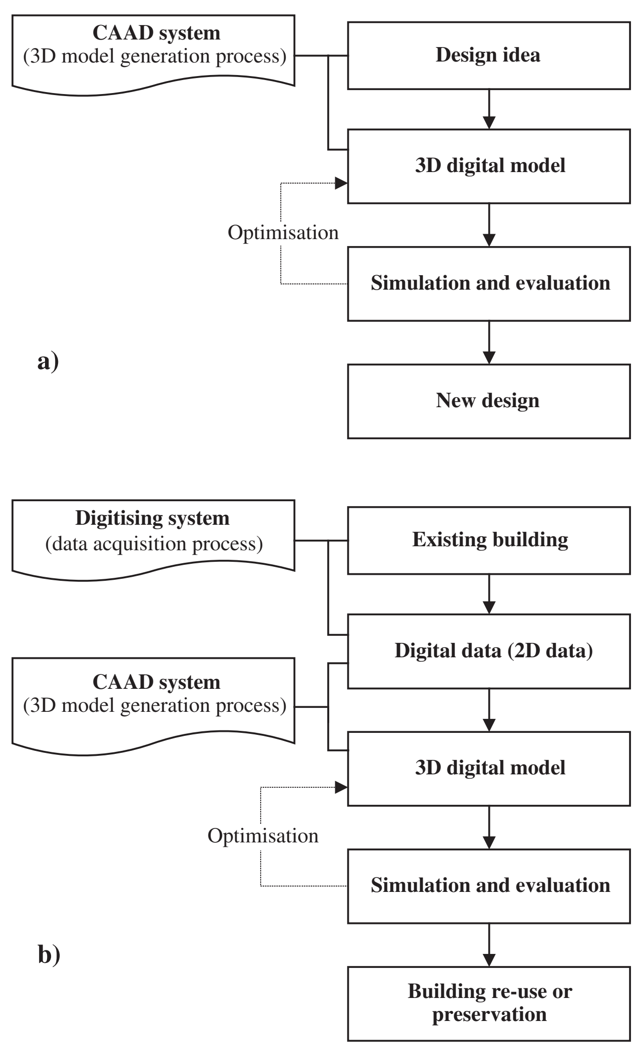

Fig. 2. Architectural design strategies. (a) Forward design. (b) Reverse design.