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Construction cost and energy performance of single family houses: From integrated design to automated optimization

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ABSTRACT

The single family home market is facing increasing challenges in managing environmental issues. The required objective of building energy performance can be achieved by limiting extra cost, integrating building design, and using the most appropriate and readily available materials. However, standard computations, such as the French building energy code used here, require vocational expertise that involves managing separate processes and numerous design variables. The design is therefore restricted to well-known techniques, especially for small constructions. In this paper, the usual stakeholder constraints and possible developments in design practice are considered through the use of real product databases and vocational tools to calculate construction costs. In the first stage, which takes into account cost and energy demand, an integrated approach to building envelope design is detailed, including a semantic system to automate the process. Then an optimization method (a genetic algorithm) is proposed to assess energy performance and the cost of the building envelope. This process is illustrated as a case study for a single family house. The results highlight various optimal solution domains specific to the case study, which can be further managed through a decision support system.

1. Introduction

Computer simulation in construction management has undergone significant development over the last few decades and is now widely used for decision support in the design stage of construction projects. Computer simulations are used for many purposes such as energy performance assessment, acoustic studies, structural calculations, facility management, life cycle analyses, architectural drawing, cost assessment, and project management and construction scheduling. Computer aided design has led to the development of specific digital representations of buildings for each assessment purpose. The convergence of these data representations progresses via an integrated representation known as a Building Information Model (BIM). At present, environmental regulations and the constraints inherent in maintaining a competitive edge are pushing designers to embrace an integrated design approach [1]. In this context, the design process needs to be a collaborative effort between all stakeholders. To enforce this integrated design approach, an EU funded education project, IDES-EDU, was set up to define the main concepts and develop cross-disciplinary expertise in integrated energy-efficient building design [2].

From a technical standpoint, the IFC standard (Industry Foundation Classes), which is an open data format, was set up to enable each expert to work on the same BIM. This avoids time consuming data exchanges between different BIMs. While BIMs have been widely studied [3], the use of this format is still not common practice in the building industry and has not yet fulfilled all expectations [4]. The holistic purpose of a standardized BIM makes it a complex data format to handle. BIM managers are needed, particularly to properly operate the BIM throughout the construction projects, and sometimes during its entire life cycle. Semantic web and ontology rules have recently emerged and have given interesting results in the handling of these complex formats by enabling semi-automatic browsing in different BIMs and databases. A brief description is given in this paper of how they were used to simultaneously browse two databases: a cost database and a manufacturer database. These semantic and ontology rules were subsequently used to set optimization design variables.

Although having several experts working jointly may be appropriate for large construction projects, this is not suitable for small projects such as a single family detached house. In France, this sector comprises around 3500 companies and each produces between ten and a few hundred houses per year, which represents 65% of the market of all newly built detached houses [5]. The design aspects of this construction sector are numerous: designing house models, dealing with material suppliers, managing construction companies, searching for clients and evaluating construction costs. Traditionally, these companies have outsourced

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specific skills such as energy performance assessment. Similarly to bigger companies, they are facing challenges resulting from the changes in building regulations and are also in need of some sort of integrated design to monitor all design criteria simultaneously during the design stage. Specific integrated design tools exist, such as the ADR tool used and detailed in Section 2.2 [6]. The ADR software computes building cost automatically, allowing quick geometry changes and providing a detailed cost assessment for the organization of the construction work. This vocational tool has been developed to include energy performance assessment and has been coupled with the French building regulation core calculation program.

Although this integrated design approach makes it easier, economically and technically, to obtain appropriate compromise solutions, it is very unlikely to give optimal solutions. The number of design variables that can be changed to improve the design, also called the design space, is simply too large to be fully explored. Instead, designers rely on their experience to improve building design with regards to their performance criteria, namely cost and energy performance here. Over the past two decades, automated optimization has been developed in building research to provide further help in decision making by determining optimal solutions [7]. It has been proven that this development gives substantial help in decision making, especially when several objective functions are considered [8]. Although various building simulation tools have optimization modules included, this method is still rarely used in building design practice. The reasons mentioned by experts include: a lack of fully integrated optimization and building simulation tools, a time consuming process of setting up both the optimization algorithm and the building model, and a lack of awareness among stakeholders of the optimization potential in building design [9]. In this paper, an approach is proposed to overcome these limitations in design and construction of single family (SF) houses. The proposed method is based on a Non Sorting Genetic Algorithm (NSGA2) that has been coupled to the integrated design tool for multi-objective optimization. A case study is presented of a cost and energy performance optimization of a SF house to illustrate the full methodology and highlight its promise with respect to building design. The methods used to build the integrated design tool and couple it with an optimization algorithm rely on data exchange using a simple building energy model (BEM) and ontology rules, respectively.

2. Energy performance and construction cost software for houses

2.1. Energy performance and building regulations

Reducing energy consumption in buildings is an important part of the European Union's 2020 climate and energy package (2009, http://ec.europa.eu/clima/policies/strategies/2020) with the main targets being a 20% reduction in energy consumption as compared to 1990 levels, a 20% rise in the share of renewable resources in the overall energy mix, and a 20% energy efficiency improvement by 2020. In the building sector, these environmental objectives were translated first in the Energy Performance of Buildings Directive (EPBD), voted in 2002, which requires substantial energy saving measures to be implemented for all new buildings and a certification scheme to be in use by 2012 [10]. A recast of this directive (EPBD-Recast) was voted in 2010 that requires net zero energy buildings to be the norm for all new buildings in the member states by 2020 [11].

In France, the EPBD has been transposed for new buildings in the RT2012 building regulation [12], which sets energy performance and thermal comfort requirements. These requirements are among the most ambitious of all member states, with a primary energy consumption requirement for heating, cooling, domestic hot water, lighting and auxiliaries of 50 kWh/(m^2.yr) for residential buildings and 70 kWh/(m^2.yr) for office buildings [13]. Rather than use simple thermal indexes calculated from the steady state and average U-values, RT2012 relies on an hourly calculation [14]. The calculation uses a transient simulation method called TH-BCE [15] and assesses the overall energy performance and thermal comfort of the building according to the climate zone. Three regulatory indexes are assessed:

✓ Primary energy consumption (*CEP*)
✓ Summer indoor conventional temperature (*TIC*), which is used to characterize hot period thermal comfort
✓ A standard index for building envelope thermal performance (*BBIO*)

The *BBIO* index is the first performance assessment index in French building regulations. *BBIO* is calculated using only the building envelope performance. It is called bioclimatic performance in the regulations [12] and is independent from the actual HVAC and other system

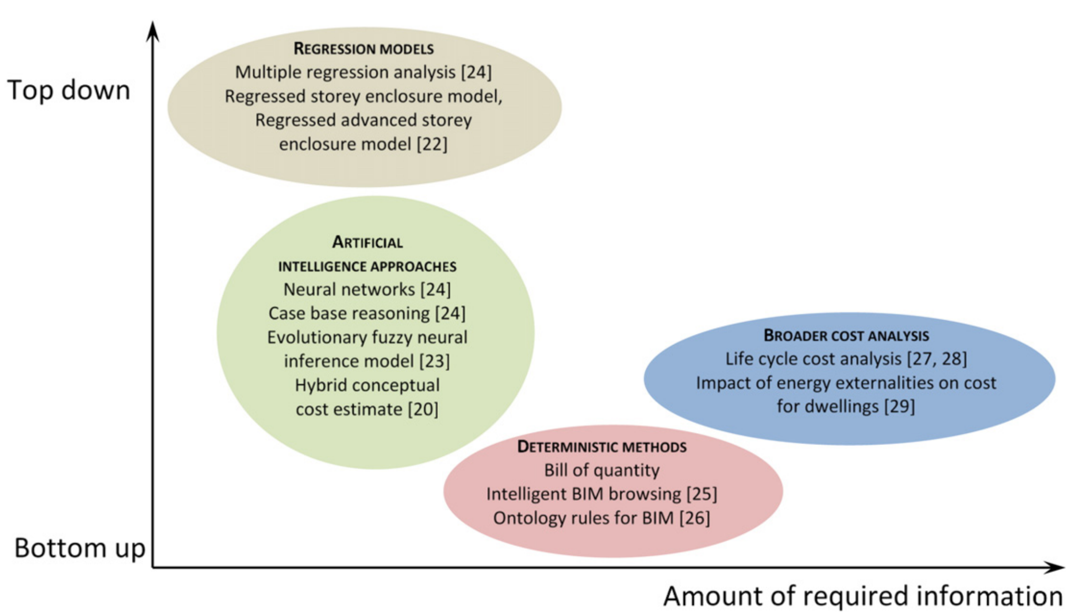

Fig. 1. Building cost assessment methodologies.