Cost Analysis and Data Based Design for Supporting Programmatic Phase

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Our paper presents research on the development of technologies and methodologies to support preliminary design phases through data based modelling. A digital parametric model informs costs evaluations and supports iterative and visual space exploration solutions. Thanks to associative modelling, the architectural conception is renewed and digital tools support design decision-making in a creative way. We propose to make project cost a design parameter through an interactive handling of a 3D geometric model that is relevant to strategic architectural intentions. In our experimentation, cost calculation spreadsheets are linked to a parametric models. An initial substructure of the building cost is defined based on the architectural concepts. The parametric tool directly informs the evaluation spreadsheet and a real time cost analysis is afforded to the designer. The tool supports the design process by displaying immediate feed back to the designer who can consider and control the financial implications of his hypothesis.

Keywords: *Parametric modelling, Cost analysis, Data based design*

INTRODUCTION

The early stage of the architectural design process simultaneously induces the definition of global intentions, objective constraints and functions with a high degree of uncertainty. Tacit rules of thumbs, reflections and objective constraints are articulated through visual and schematic representations. Options are iterated and analysed in order to support decision-making in the context of an ill-defined problem. Digital tooling, especially parametric and associative modelling, allows a visual exploration of the spatial solution while explicit feed back can be displayed and calculated in real time.

The research presents a prototyped enhancement for the early stage of design, which is proposed at the same time as an interactive 3D geometric representation and its cost calculation. Our objective is to provide a tool for supporting design decisions based on the project's specific architectural strategy and intentions. Firstly, we quickly survey the architectural design processes in the digital context. Secondly we propose an overview of the cost analysis methods developed for conceptual architectural design. The last part of the paper presents our experiment as a case study.

ARCHITECTURAL DESIGN IN THE DIGITAL CONTEXT

Parametric and associative modelling

The technological and societal changes, which characterize our time, go hand in hand with the renewal of tooling and digital design methods and processes. Step by step architectural design tooling goes from the original computer-aided design era to the that of design computation passing through formal design methods andobject-oriented software (Aish, 2013). During the last decade, digital tooling became critical for designing and parametric and associative modelling practices experienced an especially significant development. The parametric design process is based on the definition of the parameters that influence the shape. However, the shape isn't the designer's focus; it emerges from the model's interaction. The design of the project becomes the design of a process. The value modification of parameters doesn't generate a unique solution but rather a set of possibilities. Identifying and describing the variable elements in a process is called parameterisation. This process requires that the designer define both what can change and the range of possible values for each parameter. The model is not only based on metric description but more on the relations between the objects and the components that make up the form. The digital concept of associativity allows this variability in the model. The parameters list is opened to the designer's choices and intentions. The relations between the shape, structure and material are informed and interact inside the system (Oxman & Oxman, 2014).

Data based design

Parametric design is based on various simulations and digital evaluations (volumetric, structural, environmental, thermal or economic...), while the designer's intention concentrate on the project performance. Simulations are based on environmental and physical descriptions that implicate data as both input and output. Data incorporate information and knowledge with the aim to inform the design, production, building operation levels and even the physical behaviours of an architectural system operating in real-time for spatial reconfiguration or interactive energy and climate control (Bier & Knight, 2014).

These dynamics and methods implicate designers in collaborative and cross-disciplinary organisations from which Building Information Modelling (BIM) is not extraneous. Thus several disciplines and skills must collaborate to assure the architectural project's design and construction.

Programmatic and Preliminary Design Phases

Parametric and associative modelling is also adapted to the preliminary design phase and even to the programmatic phase. The level of the project's definition does not prohibit the use of parametric design and conceptual or programmatic exploration could be done starting form the beginning of the design process. The parametric model is used to explore spatial solutions and it authorizes the extraction of several representations in an interactive way. Hypothetical, architectural proposals and solutions could be represented in real time and interactively.

Thus models and representations could be shared and used for mediation and confrontation between the building owner, as well as the architectural and engineering teams. Interoperability functions usually allow exporting a model from one software to another in order to conduct dedicated simulations or calculations. Nevertheless, one of the success factors of a project is to shorten the delays between the model's construction and its evaluation by partners or experts. Parametric tools allow direct interactions and real time feed back to the designer.

COST ANALYSIS AND EVALUATION

There are commonly three main costs evaluation methods based on the project development stage: 1. The design estimate, undertaken by the designer during the project development and done incrementally step by step: Screening estimates (or order of magnitude estimates), preliminary estimates (or conceptual estimates), detailed estimates (or definitive estimates), engineer's estimates based on plans and specifications. 2. The bid estimate, done by the contractor to submit to the owner for competition, negotiation or bidding. It consists of the direct construction costs including manpower, quantities and construction procedures. 3. Control estimate, executed during the construction in order to integrate differences and added value. The estimate's accuracy is defined by the law or by the contract that exists between the owner and the design team.

Classical cost evaluation

Concerning design cost estimation, the traditional method refers to estimators, who perform the architectural cost analysis based on expertise, historical data and ratio calculations. Cost estimation and material take-off is traditionally fairly straightforward when a building is simple, with repetitive and orthogonal forms, including easily measured and counted components. An estimator goes through the architectural drawings in order to generate datasets for estimation. Based on 2D representations he calculates the quantity and size of materials, by combining the information with additional specifications. The process is time consuming, error prone and inaccurate.

Parametric cost evaluation

A parametric estimating method has been proposed and is described by Jrade (Jrade, 2004). This parametric cost model is a tool for preparing early conceptual estimates when there is only a little technical description. AACE International has developed some interactive Cost Estimating models that are intended to demonstrate some ideas behind various estimating methodologies. A parametric cost estimating model is provided. The input parameters of the model are: floor area, floor height, number of floors, percentage of area as office, percentage of area as wet lab, percentage of area as dry lab, percentage of area heated, percentage of area cooled, number of corners, interior construction finish quality, mechanical services quality, electrical services quality, escalation factor, location factor, local productivity factor. The method uses a cost accounting system, refers to a database and operates statistical evaluation in order to provide a global cost evaluation structured around ten criteria: foundations, substructures, superstructures, exterior closures, roofing, interior construction, elevators, mechanical, electrical.

Even if the method seems accurate for conceptual phases, it doesn't allow the estimation of specific architectural hypotheses. Moreover, the feedback is not prompt enough for supporting design decision-making and cost evaluations do not become a real design parameter. The architect cannot operate tests, hypotheses, and cannot make architectural choices based on tactical strategies or the main architectural intentions and schemes.

Automated cost analysis and financial optimization

Abdelmoshen (Abdelmohsen, Lee, & Eastman, 2011) proposes to automate the cost analysis of a conceptual design based on a BIM model. The process operates with interoperability and the module uses an IFC data description to extract quantity take off data and generates an XML file; this one is used by PACES software for cost estimating. A comprehensive report is proposed but the process is not realised in real time. Gerber (Gerber, ElSheikh, & Solmaz, 2012) proposes to use a genetic algorithm in order to optimize the geometric model in function of financial criteria and offers automated generated alternatives that are displayed visually and that contribute to the preliminary design decisions. The parametric and associative tools support the design process and engage at the same time visual interaction and broader exploration of spatial solutions.

CASE STUDY AND EXPERIMENTATION

In our experiment we search to make cost approximation a design parameter; our objective is to provide a direct feedback of the cost calculation through the manipulation of a conceptual 3D parametric model.

Context of the assignment

Our work is based on a real architectural commission for a programmatic study for a commercial building. The aim of our work is to accelerate the design loop especially during the programmatic and early design phases. We consider the cost analysis as one of the key design parameters and we propose an interactive and direct cost evaluation through the manipulation of the digital parametric model.

Four step methodology

We organise our work in four main steps, which allows the construction of an interactive system providing, all at once, effective and quantitative data concerning the project and a visual 3D representation of the architectural solutions (Figure 1).

Architectural specifications and intentions. The first step requires the explanation of the architectural concepts, the volumetric definition and the building systems. The main architectural intentions must be formulated, i.e.: number of building blocks, volumetric principles, number of floors and environmental strategy. For each of these items, the possible evolutionary range has to be described. Moreover, the programmatic and functional arrangement must be declared in order to specify the 3D parametric model and to get the right feed back data. Lastly, specific facilities or machinery has to be identified in order to integrate their financial impacts on the project.

Cost model specifications. The second step focuses on the construction of the cost model. Based on the preview of the architectural specifications, the cost structure is built. Following the classical cost description of a building, and going through this decomposition, each sub-criterion is listed in a spreadsheet. The traditional items are foundations, substructures, superstructures, exterior enclosures, roofing, interior construction, elevators, mechanical, electrical. The cost by unit of measure (i.e. square or linear meter) are defined in function of a price database including adjustment for location, adjustment for time (inflation), adjustment for size and number. The cost model must include the architectural specificities and strategies and is done in close collaboration with the architect in order to display the financial impact of the architectural priorities. Lastly, the specific machinery costs are included.

Digital 3D parametric model construction. The third step is to develop the 3D parametric model. In our case we use grasshopper and rhino. The digital model includes the architectural intentions and the possible evolutionary range for each geometric parameter. Few calculations are done directly in grasshopper and are displayed as a first evaluation and data control. These are functional surfaces and areas with natural lighting. Moreover the grasshopper file writes inside the cost model spread-sheet all the necessary surfaces and measurements and thus a cost evaluation is proposed in real time.

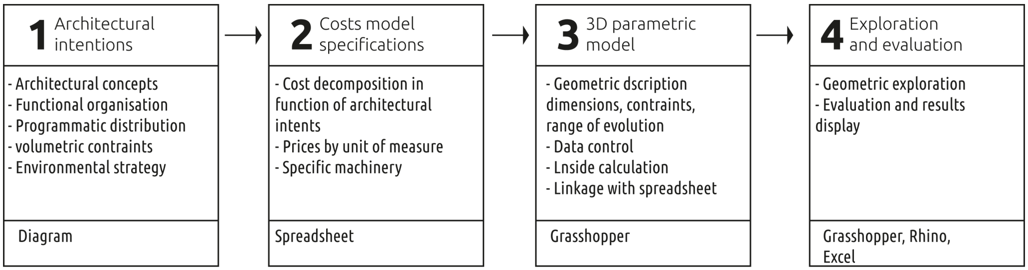


Figure 1
For step methodology

Exploration and solutions evaluations. The last step is the exploration of the spatial solutions. The architect manipulates the sliders controlling the geometric description of the form (i.e. width, height, length, number of floors for each block...) and he directly gets the resulting surfaces in function of the programmatic distribution, he visualises the areas with natural lighting and he gets a global and detailed cost evaluation of the solution.

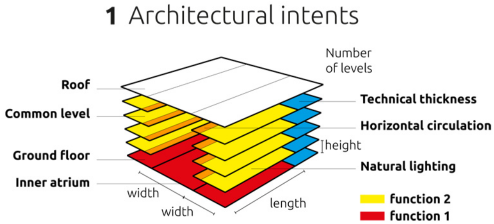
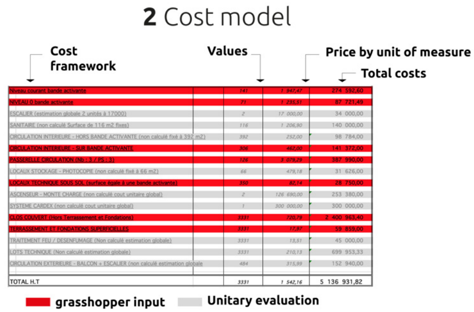


Figure 2
Architectural intentions, schematic description

Illustrative example

Architectural intentions. The architectural intentions are the construction of two blocks organized around an inner atrium. In our example, the programmatic needs are that of two main functions (fabrication labs and offices) extended by a technical thickness that includes specific machinery. The number of levels and the dimensions of each floor and the elements are all input parameters. The figure illustrates the first diagrammatic description (Figure 2).



Niveau courant bande activante		141	1 947,47	274 592,60
NIVEAU 0 bande activante		71	1 235,51	87 721,49
ESCALIER (estimation globale 2 unités à 17000)		2	17 000,00	34 000,00
SANITAIRE (non calculé Surface de 116 m2 fixes)		116	1 206,90	140 000,00
CIRCULATION INTERIEURE - HORS BANDE ACTIVANTE (non calculé fixé à 392 m2)		392	252,00	98 784,00
CIRCULATION INTERIEURE - SUR BANDE ACTIVANTE		306	462,00	141 372,00
PASSERELLE CIRCULATION (Nb : 3 / PS : 3)		126	3 079,29	387 990,00
LOCAUX STOCKAGE - PHOTOCOPIE (non calculé fixé à 66 m2)		66	479,18	31 626,00
LOCAUX TECHNIQUE SOUS SOL (surface égale à une bande activante)		350	82,14	28 750,00
ASCENSEUR - MONTE CHARGE (non calculé cout unitaire global)		2	126 690,00	253 380,00
SYSTEME CARDEX (non calculé cout unitaire global)		1	300 000,00	300 000,00
CLOS COUVERT (Hors Terrassement et Fondations)		3331	720,79	2 400 963,40
TERRASSEMENT ET FONDATIONS SUPERFICIELLES		3331	17,97	59 859,00
TRAITEMENT FEU / DESENFUMAGE (Non calculé estimation globale)		3331	13,51	45 000,00
LOTS TECHNIQUE (Non calculé estimation globale)		3331	210,13	699 953,33
CIRCULATION EXTERIEURE - BALCON + ESCALIER (non calculé estimation globale		484	315,99	152 940,00
TOTAL H.T		3331	1 542,16	5 136 931,82

Figure 3
Cost model

Cost model. The cost model is based on the following framework. The first group is composed of: ground floor, common level, roof, façade, foundations, horizontal circulation, footbridge, technical space and technical thickness. The second group is composed of: elevators, specific machinery, storage spaces and sanitary equipment. The second group costs are based on unitary evaluation. The first group costs are based on the calculation function of the prices by unit of measure and the real quantities provided by the grasshopper model. The grain size of each sub-cost could be improved (Figure 3).

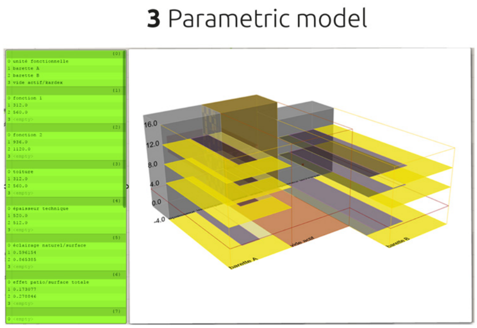


Figure 4
Parametric model

3D parametric model. The following figure shows the 3D parametric model that could evolve through the handling of the sliders. Some global calculations are done directly by grasshopper and display inside the software. Other outputs are written inside the cost evaluation spreadsheet and the cost evaluation is operated (Figure 4).

Exploration and results. Three visual project representations are provided to the designer, and each of them depicts a specific point of view of the same hypothesis. The designer understands the project through a 3D representation, a list of surfaces to compare with the needs, and a spreadsheet with the cost calculation (Figure 5).

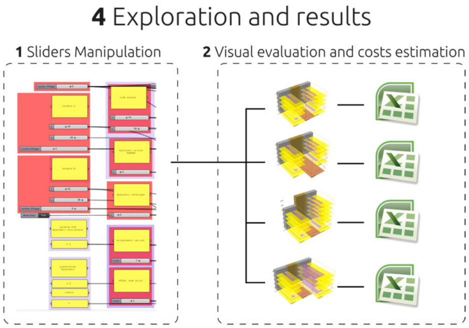


Figure 5
Exploration and results displaying

CONCLUSION

Our research describes a methodology and a tool framework for supporting the architectural design that could include financial strategy and costs analysis. We display simultaneously and in real time a 3D geometric model and the corresponding cost structure in order to make cost estimating a design parameter, in order to articulate architectural intentions and financial strategies. We tested this tool with a real commission and we would like to go further with the automatic generation of indicators that enlighten the cost's composition; the automatic construction of a cost distribution diagram is indeed our hypothesis.

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