S. Chien, S. Choo, M. A. Schnabel, W. Nakapan, M. J. Kim, S. Roudavski (eds.), *Living Systems and Micro-Utopias: Towards Continuous Designing, Proceedings of the 21st International Conference of the Association for Computer-Aided Architectural Design Research in Asia CAADRIA 2016*, 23–32.

A TALE OF TWO CITIES

A cost-driven design optimisation in Addis Ababa & Honolulu

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Abstract. A cost-driven design optimisation is introduced through two case studies: 1) a design prototype of a large scale housing community for social mix of its tenants in Addis Ababa, Ethiopia, and 2) the one of a luxurious high-rise condominium with maintaining a decent level of its maintenance fee in Honolulu, Hawaii, USA. For both cases, the computation of the optimisation was performed with regards to targeted financial concerns which are as following: 1) marketing value, construction cost, and government subsidy (incentives) for the case in Addis Ababa and 2) maintenance fee and construction cost for the case in Honolulu. Design factors are employed as a guide for computational outcomes in the optimisation of both architectural problems. The computational outcomes become the basis for projecting three-dimensional forms as design alternatives. Its application process is delineated within the integrated environment of parametric modelling applications.

Keywords. Optimisation; financial model; social mix; design feasibility; parametric modelling.

1. Introduction

Design optimisation has been employed as a rigorous methodology in the search for design solutions under an objective (fitness) function in a given problem domain with defining its boundary condition (Papalambros and Wilde, 2009). The application of design optimisation has been expanded to architecture through industrial design from mechanical or manufacturing engineering. In architecture, the design optimisation has been developed for various objective functions, such as environmental, structural, financial, and so on. Their design outcomes include building façades & envelopes, truss systems, and single & multi-family housing projects (Caldas, 2003; Shea and Cagan, 1999; Lee and Hovestadt, 2011). As the complexity of a given architectural problem increases in the optimisation process, the prioritization of the multi-objective functions is made by ranking or weighting their efficient and effective man-agement (Neema and Ohgai, 2008). The outcomes generated from the computation of the weighted functions then become the parameters for projecting design alternatives. In order to guarantee the generation of meaningful projections, design factors found in the analysis of a given site and precedent studies become critical constraints in the objective functions. The design factors regulate possible exponential growth resulting from the computational search efforts in the optimisation process. These simulated projections provide the practical value of the optimisation in architecture, and serve not only as the visual proof of the search but also as the justification of its boundary condition. In this paper, a design optimisation methodology is introduced by employing cost as the primary objective function in the development of 1) a large scale housing community for social mix in Addis Ababa, Ethiopia, and 2) a luxurious high-rise condominium in Honolulu, Hawaii, USA.

2. Addis Ababa: large scale housing development

The project site is located in one of the oldest informal settlements in Lideta, a sub-city of Addis Ababa, Ethiopia. The average family size in the city is 4.5 people in average 20 m^2 space per family. This large-scale housing development is aimed at improving these informal settlements while providing affordable housing to low-income urban dwellers with encouraging social mix. The design factors in the cost-driven optimisation for this project include a neighbourhood model and building unit types, while its financial factors include marketing value, construction cost, government subsidy (incentives). The outcomes of the optimisation are represented within a parametric modelling environment supported by Rhinoceros 3D, Grasshopper and its plug-ins in order to enhance design feasibility studies.

2.1. DESIGN FACTORS

A spatial analysis of the given site condition identified circulation, in-between spaces, and buildings as the main components of the neighbourhood model that serves as the basis of the site design. The building unit types include studio, one bedroom, and two bedroom units. The unit types are proposed for accommodating the tenants of the informal settlements and respect the multi-generational relationship found in each family unit. The project site is a 43,103 m^2 plot of land which is divided into six neighbourhood models, as shown in Figure 1. Existing circulation paths within the property are retained and improved upon for meeting municipal code. Based on the given FAR of 2 and maximum site coverage of 50%, 80,000 m^2 living space is required.

Figure 1. Site with six neighbourhoods models.

The average living area of each neighbourhood model in a given site is 13,333 m^2. Zoning regulations allow for housing and communal buildings in newly developed communities to be a maximum of 7 stories tall. The required building unit types are studio, one bedroom and two bedroom units. The building unit types are based on a 5 meter square grid. The size of a studio unit is 25 m^2, a one bedroom unit 50 m^2, and a two bedroom unit 75 m^2. The studio is the basic unit. The number of the building types and the combinations of the types are computed using g financial factors. Accordingly, the project's financial feasibility is evaluated.

2.2. FINANCIAL FACTORS

Market value, construction cost, land cost, and government subsidy (incentives) are translated into mathematical models for computing the tangible benefits for encouraging various income groups to participate in this social mix large-scale housing community. The main objective of this mathematical model is to maximize the profits P with respect to the input variables necessary for the market value (M), the total construction cost (C), land cost (L), and government subsidy (G). Government subsidy includes tax credit (T), land cost (L), construction site development (C_D). These variables are controlled by the combinations of building types. They are crucial factors in the creation of social mix. The variables used to analyse the financial factors are based upon the input data gathered from current market analysis.

$P = M – (C + L – G)$ (1)

M = *Total market value* (2)

C = *Total construction cost* = $C_A + C_C + C_D$ *such that* (3)

C_A = *Living area* (A_L) *construction cost* = $A_L \times 4{,}000$ *ETB/* m^2

C_C = *Common area* (A_C) *construction cost* = $A_C \times 1{,}000$ *ETB/*m^2

C_D = *Construction site development cost* = $A_S \times 1{,}500$ *ETB/* m^2

L = *Land price* = A_S *x 3,000 ETB/* m^2 (4)

A_L = *Living area* = $80{,}000\ m^2$

A_C = *Common area* = $36{,}000\ m^2 = S_A + H_C + V_C$ *such that*

S_A= *Semi-private area = 25% of Building area* ($0.25 \times A$) = $20{,}000\ m^2$

H_C = *Horizontal circulation area = 10% of Building area* ($0.1\times A$) =$8{,}000\ m^2$

V_C = *Vertical circulation area = 10% of Building area* ($0.1\times A$) = $8{,}000\ m^2$

M = *Market Value* = $M_x+ M_y+ M_z$ (5)

M_x= *Studio unit market value* = A_x *x 4,000 ETB/*m^2

M_y= *One Bedroom unit market value* = $A_y \times 6{,}000$ *ETB/*m^2

M_z= *Two Bedroom unit market value* = $A_z \times 9{,}000$ *ETB/*m^2

G = *Government Subsidy (Incentive)* (6)

T = *Tax Credit = 40% of Market value* = 0.4 *x* M

$G = (T + L + C_D) \times (W_x \times R_x + W_y \times R_y+ W_z \times R_z)$

such that $W_x = 1.25$, $W_y = 0.75$, *and* $W_x = 0$

W_x = *Weight value per studio unit type*

W_y = *Weight value per one bedroom unit type*

W_z = *Weight value per two bedroom unit type*

Ratio among different unit types such that $1 = R_x + R_y + R_z$ (7)

R_x = *Studio unit ratio*

R_y= *One Bedroom unit ratio*

R_z= *Two Bedroom unit ratio*

Area per unit type (8)

A_x = *Studio area* = A_L *x* R_x

A_y = *One Bedroom area* = A_L *x* R_y

A_z =*Two Bedroom area* = A_L *x* R_z

Size of each unit (9)

S_x = *Studio unit size* = $25\ m^2$

S_y = *One Bedroom unit size* = $50\ m^2$

S_z = *Two Bedroom unit size* = $75\ m^2$

Number of each unit (10)

U_x= *Number of Studio unit* = A_x/S_x

U_x= *Number of One Bedroom unit* = A_y/S_y

U_x=*Number of Two Bedroom unit* = A_z/S_z

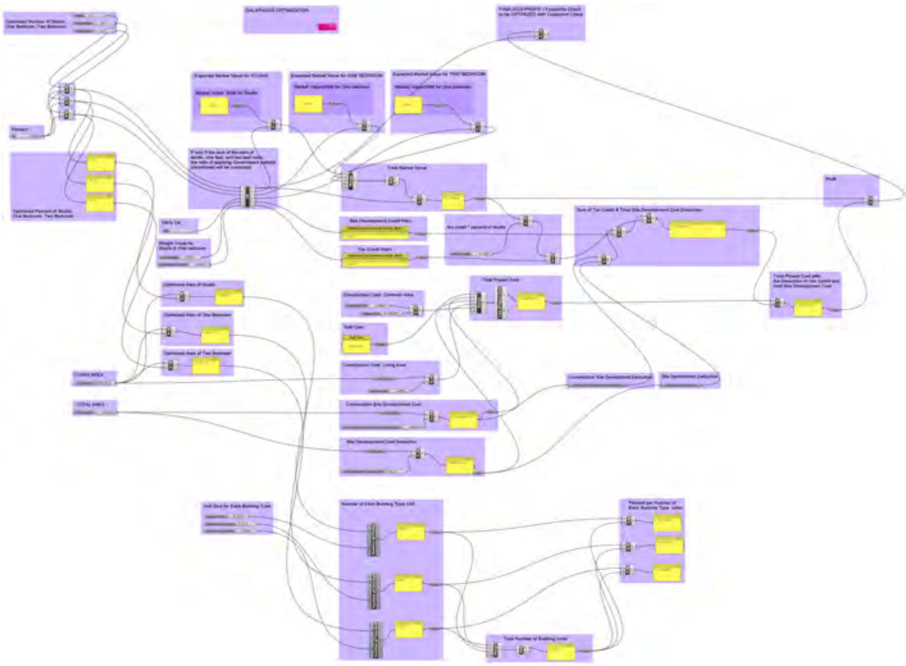

Figure 2. Optimisation in Grasshopper.

By optimising for the financial factors, it is found that, given a living area of 80,000 m^2, the studio unit type should account for 23% of given living area (18,400 m^2), the one bedroom unit type should account for 46% (36,800 m^2), and the two bedroom type should account for 31% (24,800 m^2). The computed areas out of 80,000 m^2 per each building unit type are then translated into the number of each unit type given that the size of studio is 25 m^2, one bedroom 50 m^2, and two bedroom 75 m^2. Therefore there should be 736 studio type units, 736 one bedroom units, and 330 two bedroom units. The optimised profit is then calculated to be 141,346,846 ETB, which is 22% of total project cost. The initial marketing value is 517,600,000 ETB, total project cost 629,887,867 ETB, government subsidy 253,630,000 ETB (the sum of 63% of Land cost, 63% of construction site development cost, and 63% of 40 % tax on the initial marketing value).

2.3. PROJECTIONS

Design decision making based on the financial feasibility of the project is then developed using simulated projections of design alternatives found in the optimisation process.

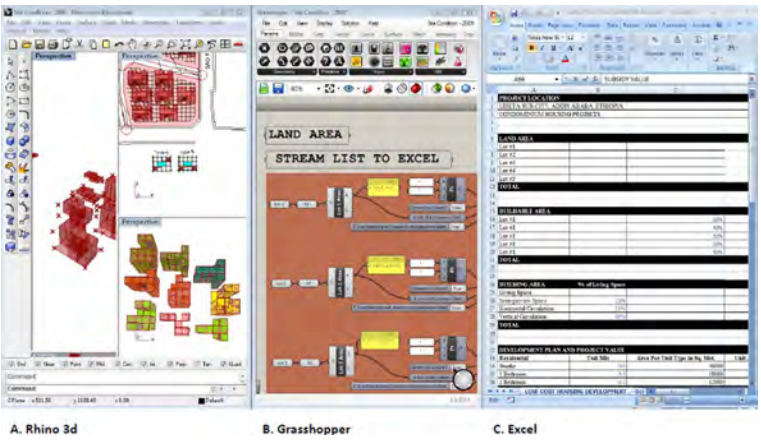

Figure 3. Integrated Projection Module.

Lot 2 is selected as one of the neighbourhood models for a demonstration as shown in Figure 4. Its living area is defined as 12,600 m^2. Using the optimised division of living area stated in 2.2 Financial Factors, there should be 116 studio units (23% of 12,600 m^2 is 2,898 m^2), 116 one bedroom units (46% of 12,600 m^2 is 5,796 m^2), and 52 two bedroom units from 3,906 m^2 (31% of 12,600 m^2 is 3,906 m^2). Then, given that a total of 504 basic units are to be assigned to Lot 2 and considering 2 people live in 20 m^2, it is validated that 1,268 people are able to reside in Lot 2. This is a 120% increase in the number of residents compared to the number of original residents 1,054 where 4.5 people live in 20 m^2. Based upon the analysis of the existing context, 5×5 m^2 grid patterns, circulations and open areas are overlaid on top of the neighbourhood model of Lot 2, as shown in Figure 4.

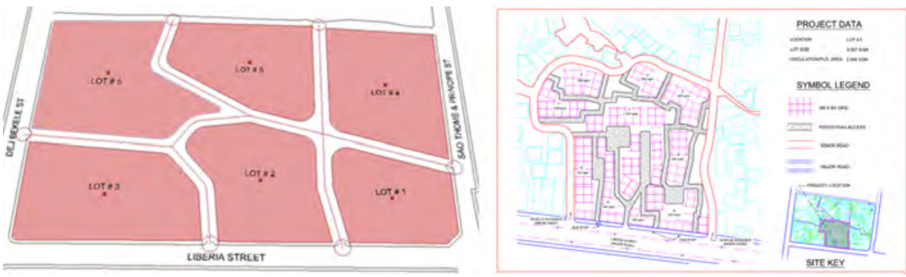

Figure 4. Generated 6 neighbourhood models and overlaid 5×5 m^2 grid patterns on Lot 2.

77 basic square units are 5 stories (G+5) and 17 basic units are 7 stories (G+7). 385 basic units are available in G+5, and 119 basic units in G+7, as shown in Figure 5.

Figure 5. Overall building height distribution. *Maps from left to right: Building height distribution; G+5 (5 stories); G+7 (7 stories); Retails (2 stories).*

According to the optimised proportion, studio units account 23% of 119 basic units (28) when a basic unit is 5m x 5m and its size is 25 m^2. One bedroom units account for 46 % (56 basic units), and two bedroom units 31% (36 basic units). This means that G+7 should have 28 studios, 28 one bedrooms, 12 two bedrooms. Each level needs 4 studios, 4 one bedrooms, and 1 or 2 two bedrooms. The combination of three building unit types, horizontal & vertical circulation, and semi-private area are defined in as shown in Figure 6.

Figure 6. *Three building unit type combinations with circulations.*

The projections of the building unit types in Lot 2 are generated in Rhinoceros 3d with Grasshopper are shown in Figure 7.

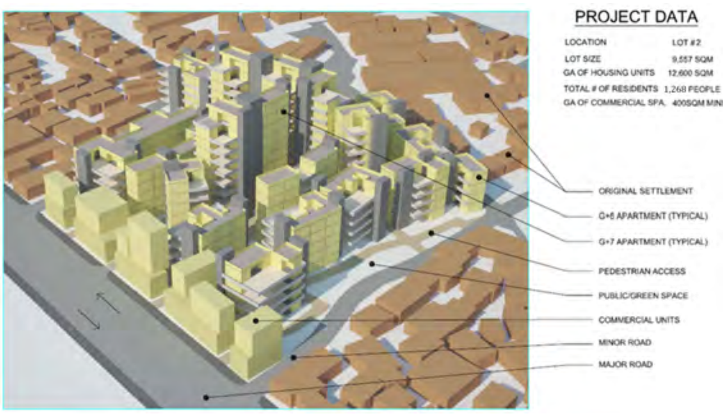

Figure 7. *Projected Buildings in Lot 2.*

3. Honolulu: high-rise condominium

In the real estate industry, the optimisation of building maintenance fee along with maintaining maximum tenant living condition is regarded as an instrumental Unique Selling Proposition (USP) for increasing a building's market value. A design prototype for a condominium in Honolulu, Hawaii is projected using a cost-driven design optimisation methodology. This cost-driven optimisation integrates an early stage design synthesis for a high-rise condominium with its construction cost estimation when its design alternatives are constrained by design factors known to optimise for its maintenance fee. When the maintenance fee is adjusted by the design factors, the optimisation is focused on the construction costs.

3.1. DESIGN FACTORS

Design and financial factors are defined through an analysis of the maintenance fee for 17 buildings in Hawaii and 6 buildings in Florida. The design factors are the possible variables found in a building's design which decrease expenses and increase incomes while maintaining a high level of user satisfaction and building security. These design factors include 1) building floor plans, sections and site plans, 2) number of units in a building, 3) land acre size, 4) location and land value, 5) year, 6) amenities, and 7) extra revenue facilities.

3.2. FINANCIAL FACTORS

Maintenance fee, and construction cost are translated in mathematical models in order to check financial feasibility of the condominium project. Total project cost is defined as a constant value in the computation of Net Present Value (*NPV*) which represents Internal Rate of Return (*IRR*) in the current marketing value estimation for the high-rise condominium. With maintaining the decent level of maintenance, a construction cost is regarded as a variable for minimizing the total project cost. The fitness function on the design alternative is focused on minimizing $f(_i)$ with respect to the input variables necessary for the total construction cost (T_i) of the design alternative with subject to the set of construction tasks constrained by the design factors and the input variables necessary for each task. Given i = index of task, p = project id, D = total direct field cost, and H = total overhead cost,

$$f(i) = M_p + \sum_{i=1}^{n} T_i \quad (11)$$

$$T = \sum_{i=1}^{n} T_i = D + H \quad (12)$$

$$T_i = \{F_i + Q_i(M_i + E_i + W_i L_i)\} + H_i \quad (13)$$

Computation of the fitness function starts with gathering the cost of individual tasks. The input variables of individual task includes field supervision (F_i), materials (M_i), equipment (E_i), labor (L_i), wage rate (W_i), overhead (H_i) and labour cost per each field work (Q_i).The cost of the individual task (B_i) is calculated according to “Building Construction Cost Data” in MasterFormat 2009. In the middle of the computation, various design options, including size, numbers, types, and construction methods per each task are searched for in order to minimize the total cost.

3.3. PROJECTIONS

Using the given formula, one of the condominiums with high maintenance fee in Hawaii is selected and its design alternative is developed with the goal for minimizing its construction cost as shown in Figure 8.

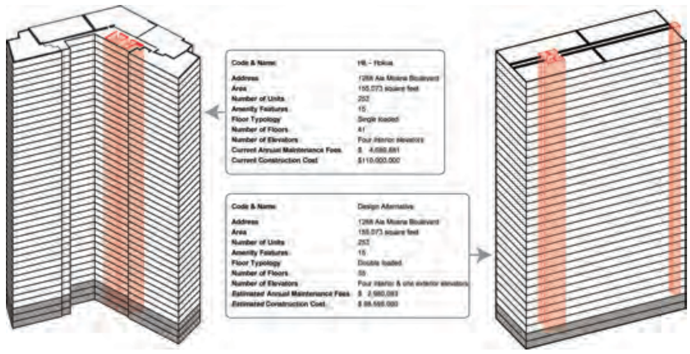

Figure 8. (a) H_8 – Hokua in Honolulu, (b) a design alternative by the design factors.

The construction of the original design was \$110,000,000 with \$ 4,689,881 annual maintenance fee when it has 1) single loaded corridor, 2) 41 floors, and 3) four interior elevators. By combining the design options an optimised alternative is then generated in Rhinoceros 3D using Grasshopper. This design alternative has 1) double loaded corridor, 2) 35 floors, and 3) four interior elevators & one exterior elevator. The estimated construction cost of this alternative is estimated to be \$ 98,595,000. Its maintenance fee is the average of other buildings' which have design factors similar to the ones in the alternative. This comes out to be \$ 2,980,093. Therefore this design alternative finds a 10.3% reduction in its construction cost build and a 36.4% reduction in its maintenance fees when compared to the original building.

4. Discussion

A cost-driven design optimisation was applied to 1) the design of a large scale housing community in order to maximize a project's profit and encourage social mix in a community, and 2) the design of a luxurious high-rise condominium prototype in order to minimize a project's construction cost while maintaining a decent maintenance fee. The outcomes of the large scale housing community project in Addis Ababa were 1) an optimised profit which came out to be 22% of total project cost, 2) the social mix regarding building unit types (studio units: 41% of total units, one bedroom units: 41 %, and two bedroom units: 18%), and 3) a 120% increase in the number of residents. The outcomes of the high-rise condominium project in Honolulu were 1) a 10.3% reduction in the building's construction cost and 2) a 36.4% reduction in the maintenance fee. The proposed cost-driven design optimisation was composed of 1) design factors, 2) financial factors, and 3) projections. The design factors were defined using the analysis of existing site context and precedents. The possible exponential growth of the computation was able to be regulated by the design factors. Furthermore, the design factors were used as the guiding force when defining the boundary condition of a given project. The outcomes computed using the financial factors became the basis for projecting simulated design alternatives. These projections provided interactive responses to various financial changes, and therefore could be utilized by not only designers but also developers in order to make more informed design decision.

Acknowledgements

This project is supported by the extramural research fund from Samkoo Hawaii, LLC.

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