

Addis Building Configurator

Computational design tool for efficient planning of mass housing in Addis Ababa

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Abstract. *The paper presents ongoing applied research on the development of a computational design tool addressing planning deficiencies in the city of Addis Ababa, Ethiopia. Because of increasing population pressure and a lack of planning resources, Addis Ababa is clearly in need of new efficient planning solutions. The tool proposed utilizes and combines different generative design methods in order to increase the efficiency of planning and construction processes. The paper discusses design goals and the implementation strategy involved.*

Keywords. *Design tool; evolutionary optimization; generative system; developing countries.*

INTRODUCTION

The housing situation in Addis Ababa

The capital of Ethiopia, Addis Ababa, is facing an increasing housing deficit. According to UN criteria, 70 - 80% (UN-HABITAT, 2008) of the existing housing structures can be defined as slums and the city is facing exponential population growth with a further 4 million people expected to live in the city by 2025.

Against this background, the Ethiopian government has developed a Grand housing program for the erection of multi-storey habitation units, colloquially termed “condominiums”. These are rapidly spreading over the city with roughly 171,000 housing units built since 2005 (UN-HABITAT, 2011) and another 350,000 are planned by 2012. The main target groups of the program are low-income households as 70% of the population in the city

falls into this group. Despite the huge effort invested in increasing the construction speed, the gap between housing supply and demand is still getting wider. The enormous population growth obviously requires a housing strategy that goes beyond the scope of the current approach. In Addis Ababa alone, 300,000 housing units are still required to meet the current deficit (Haregewoin, 2007) not considering the 23 million new citizens expected over the next 10 years.

The second main problem is that the proposed condominium housing fails to accommodate the target group of citizens the housing program aims to address. More than 70% (UN-HABITAT, 2010) of these newly built social apartments have been aban-

done by original “low income” owners and have been rented by middle-income population. This is mostly caused by the real estate market situation which does not reflect the social distribution in the Ethiopian population nowadays. These new housing units are, despite governmental policies to the contrary, immediately consumed by the rising middle income segment of society (Bigsten et al., 2005). The only solution for this unwanted social segregation is saturation of the housing market to relieve the pressure and allow the urban poor to increase their living standards. The struggle to meet this challenge has to do with the financial resources and also the lack of free space available. The construction costs (61 USD/m²) are already at such a low level that this could hardly be a target of criticism or improvement. The spatial deficit in Addis caused by inefficient land use and is the issue where improvement can and must be done. Examining the current condominium program, it becomes obvious that not the building itself, but the urban design is the weak point of the project. Density levels that are even below the original single-story housing, non-functional public space and a lack of connections to the existing urban structure (Kifle, 2008) are another common point of criticism with regards to urban design.

Conclusion

When we take a closer look at almost all the observed deficiencies of the proposed housing program, we find one common cause behind them. Social segregation, cultural inappropriateness, insufficient public participation, disregard of urban relationships, and typologies that are unable to accommodate the spectrum of the existing heterogeneous social mix are all problems that are not the result of poor implementation, materials or construction but the result of planning. To be more precise, the problem is actually the absence of planning. The standard planning process is regarded as too time consuming, with the consequence that shortcuts are taken to speed up construction. The resulting inadequacies are most apparent at the urban design scale where the unique context and the urban rela-

tionships inevitably require an extensive planning process which can be hardly be substituted just by applying typological solutions.

GENERATIVE PARAMETRIC PLANNING TOOL

Based on the current status of the Ethiopian inner-city housing policy the “Addis Building Configurator” project proposes an alternative approach to the planning process. Given the fact that standard design methods are unable to react within the time constraints and enormous production pressures currently prevailing in Ethiopia, our approach aims to support them using a computationally aided generative system to increase the quality and efficiency of planning. In response to the deficiencies of the current housing program, we have identified the following criteria that need to be considered and improved in the proposed generative system. These criteria can be differentiated according to those that influence the quality and those that influence the quantities of the design solutions. Criteria influencing the quality are:

- Urban context – the proposed system should enhance the ability to respond to specific site conditions, transport flows, views (orientation), regulations.
- Closed/open space relation – the culturally strong relationship to outdoor space should be reflected in the architecture, since many activities require this (slaughtering animals, meal preparation, etc.)
- Public/private space relations – this should guarantee that different types of open space typology are present, which is currently not the case.
- Flexibility – housing needs to be responsive to changes that are already happening in all sectors of life in Ethiopia and should be able to accommodate quite different demands in 20 years from now. If low costs and efficient solutions are to be maintained, they need to be built in such a way that the buildings are able to adapt and do not have to be replaced.

- Daylight – sufficient access to light and protection against overheating are basic criteria for making any space usable and livable.
- Diversity/heterogeneity – the social mixture currently seen in slum neighborhoods is considered an important factor for stabilizing society. Based on previous experience, we believe this should be addressed by architecture (heterogeneous living conditions) rather than politics alone (regulation, lottery etc.).

Criteria that influence quantities are:

- Density – provides a good measure about how efficient the valuable free space is used. Higher plot usage while maintaining living standards is the way to increase housing capacity. This enables the urban poor to stay rather than be pushed out by higher earning groups in search of for better housing.
- Cost efficiency – lack of natural resources and one of the lowest GDP/capita in Africa make it necessary to build cheaply. At this point we should take the current development as a positive example.

Of course, this list is not an exhaustive attempt to describe good planning solutions. Rather, these criteria should be seen as list of critical issues for the given context that deserve special attention and therefore will be discussed more in detail in this paper. At the current stage of development we are focusing on generating building forms and constructions that suit these criteria and create good preconditions for further planning steps. The following section describes a concept for the implementation of these criteria using a generative system.

Generative system

Generative systems in a broad sense can be powerful tools for handling complex design tasks in a very time efficient way, but require careful and elaborate research and development. For such these tools to be effective, they must save more time and resources in the design process than have to be invested in their development. This is the core argument for using generative systems as a design method in Addis

Ababa where up to 800,000 new housing units have to be built in next 10 years. This fact will allow extensive research and development to still be extremely cost-effective.

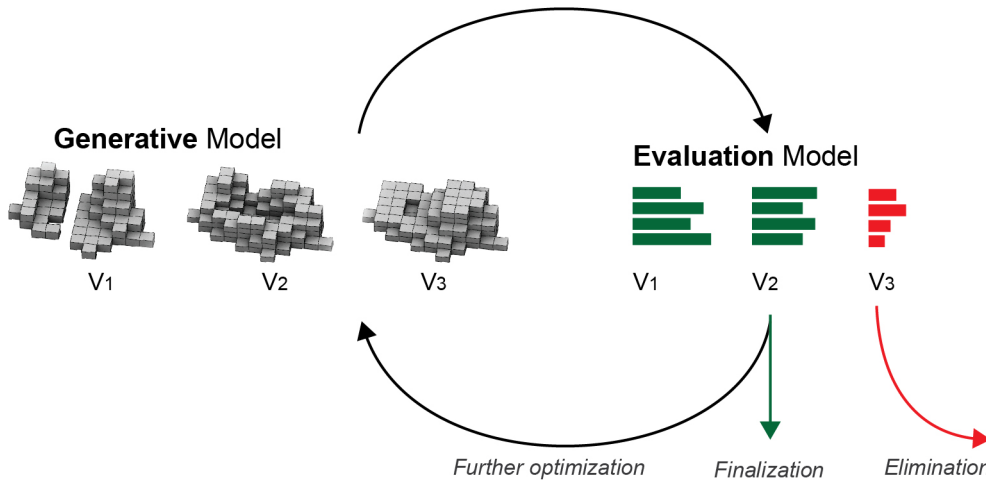
When developing a generative system, the difficulty lies not in generating new designs, but in selecting those that are worth further consideration by a human user or the system itself for further development ([Eckert et al., 1999](#)). The proposed generative system is based on a generative model (GM) responsible for the generation of design variants and an evaluation model (EM), in which the evaluation criteria and their relative importance are defined (Figure 1). The system can generate all the alternative designs that are consistent with the rules and algorithms described in the GM to map the entire solution space. These rules, algorithms and heuristics can be seen as knowledge embedded in the GM, whose role is to keep this solution space within manageable bounds. Since generative systems are generally computationally very expensive, restricting the design space is useful because it makes it possible to obtain a set of solutions in a reasonable time or to even make the whole process interactive.

Every architectural design has to meet some specific requirements and criteria. Defining what these constraints and quality criteria are is the key task in developing a generative system. Design criteria applicable to generative systems in general, are quantifiable criteria such as cost, material use, insulation etc. Nevertheless, the building configurator will be designed in such a way that human interaction is possible which makes it possible to incorporate “soft” criteria in the design process. Such an approach is quite usual in the conception of generative systems, where not all performance criteria can be quantified ([Donath et al., 2012](#); [Elezkourtai, 2004](#); [Eckert et al., 1999](#)).

Generative model

In order to generate a building shape that fulfills the criteria mentioned above, we need to integrate them in the GM, EM or both. In the GM we search for procedural algorithms, which can satisfy specific

Figure 1
Schematic functionality of
the implemented generative
system.



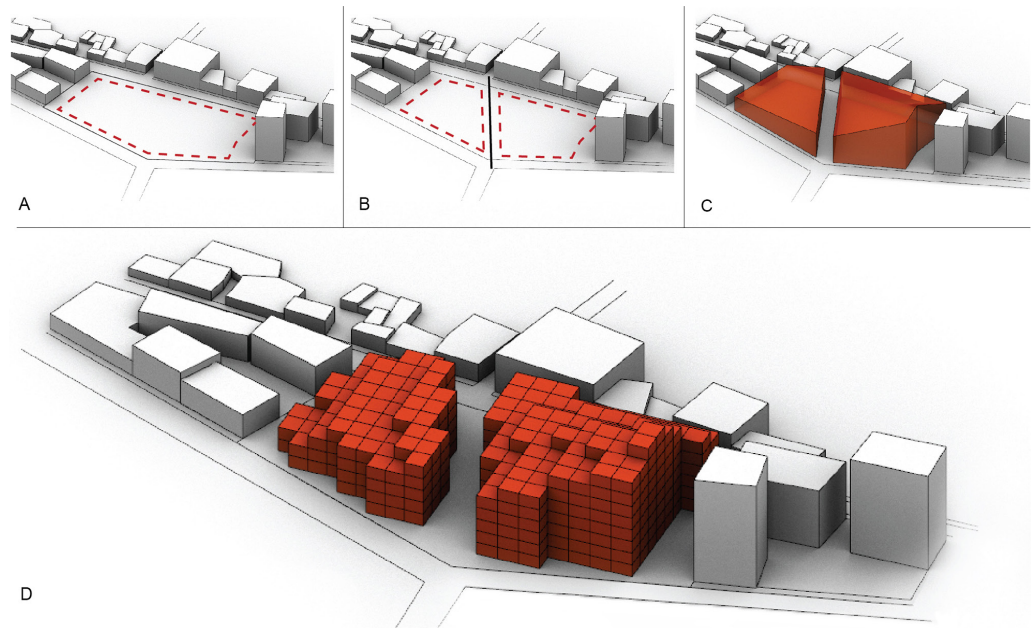
criteria in such a manner that only clearly unsuitable design variants are excluded (Bentley and Corne, 2002). The more criteria that are included in this step, the faster the generative system will be able to offer optimal solutions. Criteria which can't be described by such an algorithm but can be measured and evaluated will be integrated in the EM. In the following we describe the algorithms in the order in which they are executed. Once an optimal solution for a problem as covered by a specific algorithm is found, and no input criteria have changed, there is no need to re-compute it. Based on this key, some algorithms are executed only once at the start of the generative process (in pre-process; Figure 2) while the others are part of the optimization loop and are responsible for generating variants (Figure 3).

Plot subdivision: The first step is the subdivision of the plot in order to maintain existing urban relationships, heterogeneity and cost efficiency. When generating buildings on a new area there may be a need to divide the given plot into smaller ones. One reason may be that we want to generate housing with different parameters (increasing heterogeneity). Another reason might be that the construction will proceed in several time stages so we need to generate fully independent housing blocks. The

subdivision is based on the Voronoi diagram evolutionary-optimized by the following five criteria. First we have to define number of plots, and secondly we define the size of individual plots. For the later steps (modular, economical construction) we need plots with angles between single line segments that define their border that are as close to 90 (or 0) degrees as possible. Therefore the third criterion is the deviation from this "ideal" angle. Fourthly, narrow plots should be avoided because of their limited usability. To do this we employ simple geometrical analysis to subtract all spaces from the original plot where the offset to a border line lies outside the plot. Lastly, all relevant street connections, defined by the user, are considered in the process of subdivision. For merging all criteria in one fitness value, deviations, re-mapping and non-linear functions are used.

Maximum build volume (Urban regulations, relations): In order to determine the space which will be used in further steps for generating the building form the official urban regulations and relations (Donath and Lobos, 2009) are considered. There are five regulations (Abraham and Hiyaw, 2010) included in the whole generative system from which two are integrated in the GM and three are part of EM. The first rule is defining the usable space in vertical direc-

Figure 2
Pre-processing algorithms
implemented in GM. A) Buildable plot area B) Urban relationships C) Height regulations (max building envelope) D) Maximal Voxel cloud.



tion. It is restricting the maximum building height. The second one is regulating the maximum vertical angle covered by building which is measured from middle axis of neighboring streets. Additionally the user can define areas which shouldn't, or have to be covered by buildings in order to respect important views, connect streets or build directly on street line.

Grid positioning (cost efficiency, flexibility): The lesson learned from the current condominium program is the great impact of modular construction on overall building costs. We embedded this principle as the core element of the GM by using a 3D Voxel-grid as the basis for all geometrical operations (see next section). After the maximum buildable area is defined, the grid has to be placed in such a way that the highest number of grid cells fits into this area. Therefore the grid is rotated according to the dominant direction of the polygon. The dominant direction is calculated by adding all parallel vectors of the plot borders and then choosing the longest vector. After this, we move the grid in a series of steps in

two directions to figure out the best position.

Voxel cloud: The last step of the generative pre-process is the creation of a voxel cloud based on the maximum building volume on the optimal grid position. A similar model for building generation was used by Dillenburger et al. (2009) or Watanabe (2002). This voxel model serves as the basis of the generative model. The model is particularly suited for our purposes, since we propose a modular building structure with elements of identical dimensions. Furthermore this model makes it possible to generate solutions with different topological properties. Consequently, solutions with many individual buildings can be generated as a single volume.

Voxel cloud mutation: Our strategy for variant generation is based on the addition or elimination of voxels in the input model. This process could be described as directed randomness because of a few restrictions that help the process move in the right direction (towards better results). The first decision we make is whether a voxel is added or removed.

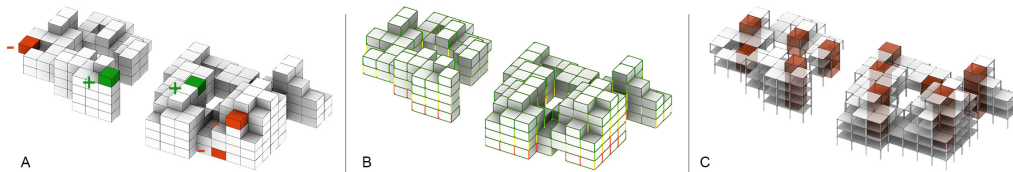


Figure 3
Exemplary algorithms
implemented in GM. A) Voxel
cluster mutation B) Structural
analysis C) Vertical circulation.

There are two values which could be derived from the urban regulation code, setting up the minimum and maximum floor area. This is called the minimum density and maximum floor area ratio (FAR). Comparing this number to the floor area currently offered by our voxel model, we can decide if the next step will be removal, addition or random choice.

Another set of restrictions defines the location where voxels can be added or removed. Considering light, construction, ventilation, circulation or contact to exterior space it makes little sense to remove voxels from inside of the building form creating cave-like holes. To avoid this, voxels can only be removed from the building boundary.

Structural elements: In order to ensure future flexibility, to speed-up construction and lower the costs of our design, we propose the use of a prefabricated reinforced concrete skeleton as a construction system. In order to do this, the voxel building model is transferred into single parts representing columns, beams and floor slabs. Considering that in every construction different forces and stresses apply in different places, it makes less sense to use the same structural elements everywhere. Therefore we do a structural analysis of the whole structure and choose an appropriate solution from a catalogue of prefabricated elements which is being currently developed. This ensures material savings which, in Ethiopia especially has a huge impact on cost as almost all construction materials are imported.

Other algorithms like the positioning of vertical circulation (Dillenburger et al., 2009), restricting the number of voxels according to a given space program or the distribution of particular housing units in the given geometric building envelope (Donath et al., 2012), are further criteria to be directly implemented in the GM. Since these algorithms do

not define the final design, but rather narrow the solution space by excluding those clearly unsuitable ones, an additional evaluation model is defined ensuring certain criteria through optimization.

Evaluation model

The final group of criteria shares a common characteristic: it is easy to evaluate if a design solution fulfills them or not (e.g. cost, floor area ratio), but we cannot precisely define any deterministic algorithm which leads to an optimal solution. Hence these criteria are implemented in the EM and the process of finding an optimum is driven by an evolutionary algorithm (EA). EA are particularly useful for our purposes because the optimization process needs only a few instructions on how to improve a solution (Rechenberg, 1994). Here, we briefly discuss the currently implemented criteria.

To fulfill all necessary regulations required by the official urban codes and to ensure good use of a given space, we have to evaluate those that are not implemented in GM. These are: build area ratio (BAR), floor area ratio (FAR) and minimum density. As already mentioned, there are some mechanisms which increase the probable improvement of these criteria, but do not guarantee their full satisfaction. Cost efficiency is another important criterion which is relatively easy to evaluate. Currently we consider only material and fabrication cost based on a structural analysis made in the GM. Afterwards, the costs are considered in relation to the resulting floor area (without vertical circulation). This is only an approximate assumption of the future costs efficiency but as a relative value it is very useful for the optimization process.

One of the basic requirements on living space is sufficient lighting. Because of Addis Ababa's geo-

In order to obtain solutions that reflect the social and cultural background, different degrees of privacy (private, semi-public, public) in the urban space shall be ensured. The distinction between public and semi-private space is done according to visibility graph analysis ([Turner et al., 2001](#)). First the analysis grid is set up and then the visual step depth to the surrounding streets is measured for every grid cell. This is then used to define which cells are sufficiently visually segregated to allow semi-private space to emerge, but also not too segregated to avoid creating uncontrollable spaces. The rest of the grid cells will eventually be part of public life. The entire built-up area is considered to be private space.

Finally, according to the chosen criteria one design option is selected. This is done either by the designer or the generative system itself. Afterwards the

CONCLUSION AND OUTLOOK

The development of the tool is an ongoing research project with international collaborators. The evaluation methods, criteria and building parameters are still under development.

However, despite the potential offered by computational aids for designing, the biggest challenge lies in choosing the right, locally appropriate criteria and their computational representation. Currently only the building form is generated but for future development living units layout should also be in-

egrated into the system. This would give us more detailed designs and also better conditions for optimization.

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