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TOWARDS CUSTOMIZABLE PROTOTYPE: A CONTEXTUAL APPLICATION OF BUILDING INFORMATION MODELING IN THE ARCHITECTURAL DESIGN STAGE FOR THE 40/60 HOUSING PROJECT OF ADDIS ABABA

By

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Declaration

This thesis entitled ***"TOWARDS CUSTOMIZABLE PROTOTYPE: A CONTEXTUAL APPLICATION OF BUILDING INFORMATION MODELING IN THE ARCHITECTURAL DESIGN STAGE FOR THE 40/60 HOUSING PROJECT OF ADDIS ABABA"*** is my original work and has not been presented for a degree in MSc. In any other university, and all the sources of material used for the thesis have been duly acknowledged.

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Certification

The undersigned hereby certify that a thesis entitled ***"TOWARDS CUSTOMIZABLE PROTOTYPE: A CONTEXTUAL APPLICATION OF BUILDING INFORMATION IN THE ARCHITECTURAL DESIGN STAGE MODELING FOR THE 40/60 HOUSING PROJECT OF ADDIS ABABA"*** has been read and recommended to EiABC, graduate studies for acceptance, in partial fulfillment of requirements for the degree of Master of Science in Masters for Advanced Architectural Design (MAAD)

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Abstract

This paper aims at developing a method of using Building Information Modeling (BIM) technology to bring about mass customization (MC) to the 40/60 housing prototype of Addis Ababa. The 40/60 housing is the 'middle income' typology in the government led housing program called integrated housing development program (IHDP). In IHDP, prototype designs are made in 2D based traditional system and continuously repeated in different sites with minor modifications.

By using BIM technology, the 40/60 prototype design is (re)developed with customizable parts that change based on the specific site conditions. The customization focuses on responding to external factors like site slope conditions, building orientation, the level of need of commercial floors based on location and visual monotony. The options are designed considering the context of labor-intensive construction system that the IHDP has employed. The customizable prototype design developed in the research has been finally test designed in a small neighborhood site in Addis Ababa.

Key words

Mass customization, building information modeling, integrated housing development program, 40/60 housing

Definition of terms

Here are the intended definitions by the author of the most commonly used terms throughout the thesis work.

Customizable: with the ability to change in response to different forces that demand variation.

Prototype: an entity or a design that is developed in an ideal situation but with the aim of using it repeatedly in different scenarios.

Contents

List of Figures

List of Tables

List of Acronyms

AEC: Architecture, Engineering, Construction
BIM: Building Information Modeling
MP: Mass Production
MC: Mass Customization
CA: Cellular Automata
IHDP: Integrated Housing Development Program
DB: Design Build
DBB: Design Bid Build
CM@R: Construction Management at Risk
IPD: Integrated Project Delivery
HAS: Housing Agency System
FIS: Finishing information system
NS: North-South; EW: East-West; NWSE: Northwest-Southeast
MSEs: Micro and Small Enterprises
MEP: Mechanical, Electrical, and Plumbing

1 Introduction

1.1 Background

The industrial revolution of the 19th century gave rise to the concept of mass production. Mass production is about efficiency and cost effectiveness through repetitive production of identical items. This idea of mass production which was primary used in other sectors like Toyota Car Company was later brought to standardized mass housing programs. However standardization in mass housing was criticized for its lack of variety; creating boring monotonous repetition; disregard for individuality and individual needs; insensitivity for micro climate and site specific features to mention some. (Dye, 2004)

One of the early critics of standardization of mass housing Davis (1997) argues the idea that Standardization and replication of buildings is the best way to lower housing costs is partly a myth.

> ***It is true that standardization can produce efficiency but the cookie-cutter approach to housing is what has doomed so many public housing projects. The key is to find means including architectural variety and diversity within recurring building systems.***(Davis, 1997 pp 4)

Despite the fact that standardization increases efficiency, there is a need to find a way of adding variety resulting from different forces of a site. And this should happen without compromising the efficiency of the system.

With the advancement of building information technology coupled with computer controlled manufacturing systems a new era has come in the way mass housing is being approached. This advancement enabled mass customization, which is the production of diversified items in mass at the efficiency and cost of mass production.

> ***"Things used to be made to order and made to fit. But they were labor-intensive and expensive. Mass Production came along and made things more affordable, but at a cost — the cost of sameness, the cost of one-size-fits-all. Technology is beginning to let us have it both ways. Increasingly, we're getting more***

personalization at mass-production prices. We're moving towards mass customization." *Robert T. McTeer Jr cited in* (Dye, 2004 pp 217)

For instance in the case of standardized mass production, the efficiency and cost effectiveness of window panel production depends on the repetition of identical items. But in mass customization, the window panels can have diversified shape, size etc. at the efficiency of mass production because of the computer controlled design and production.

But mass customization in mass housing is yet a developing concept. There are ongoing researches and experiments trying to bring the concept of mass customization in mass housing. (Shin, An, Cho, Kim, & Kang, 2008; Benros & Duarte, 2009; Rocha, 2011; Bergin & Steinfeld, 2012). What is common to all of the researches is the idea of using high-tech production system to bring about diversity and specificity of the housing units in the mass housing. But for developing countries like Ethiopia where the construction industry is not yet that advanced, there is a need for a contextual system that considers the technological level of the local AEC industry to start bringing diversity and specificity in mass housing.

A huge housing deficit in urban Ethiopia (900,000 to 1,000,000 according to government estimate in 2011) combined with one of the highest rates of urbanization in the world (3.8%) and rapid population growth with a prevailing urban poverty has placed enormous strain in providing affordable housing in Ethiopian cities especially in the capital, Addis Ababa. (Un-Habitat, 2011) To alleviate this problem the government initiated Integrated Housing development Program in 2005. In the first five years of the program, 171,000 housing units were constructed and transferred to beneficiaries(Un-Habitat, 2011). There is a plan to construct 750,000 housing units in the years 2015 to 2020 in urban areas alone (Asrat, 2016).

From IHDP, 40/60 housing was chosen for many reasons. First of all, being planned for middle income the 40/60 program is assumed that it is in better financial stand than 10/90 or 20/80 programs. Parallel to solving the housing deficit, the 40/60 housing is also planned to make the image of the city better through better visual design and quality finishing. 40/60 program would be easier to start with in this paper because it is a program on the start and no single house has been transferred until the time this paper is compiled, which makes the analysis of the sites manageable within the time frame of this thesis.

1.2 Statement of the problem, research objectives and research questions

1.2.1 Statement of the problem

Nowadays, it is common to see hundreds of relentlessly repetitive housing blocks in the sites of IHDP. Very few typologies are designed and repeated in large scales with minor modifications to adapt them to their specific site (Un-Habitat, 2011) (Kifle, 2008). Although there are attempts to adapt the typologies to sloppy sites or to include commercial floors when the blocks are facing main streets, the modification process is taking too long and it is usually far from getting precise documentation and quantification of the changes(Teshome, 2016). While visiting the constructed neighborhoods one can notice that there is no much variation if the buildings face the harsh southwest sun or if the moderate south north orientation. The blocks are treated similarly whether they are in a chaotic street or a quiet neighborhood.

The problem is two sided. On the one hand there are very few customization attempts to adapt the design of housing prototypes to their specific site conditions and for the different factors that demand variety, on the other hand those very few design customization attempts are taking too long and are usually far from getting precise documentation and quantification of the changes(Teshome, 2016).

With the labor-intensive construction system of IHDP, for reasons of job creation and lack of technological advancement, it is hardly possible to move to mass customization of mass housing at least for the coming years. However, with the government plan to construct 150,000 housing units per year (Asrat, 2016), it would be too late to wait for technological advancement in the construction sector to bring about some variety and specificity in the mass housing neighborhoods.

1.2.2 Research question

How could Building Information Modeling (BIM) technology facilitate in enriching the 40/60 housing prototype design of Addis Ababa with inbuilt customizable parts considering the current local context of traditional-2D based, rapid and labor-intensive construction system?

1.2.3 Research Objective

1.2.3.1 General objective

This thesis aims at developing a method of designing prototypes that have inbuilt customizable parts using Building Information Modeling (BIM) platform. Selected site factors that demand customization in the prototypes like building orientation and topography are used as samples to explore the process of development of customizable prototype. This new method of designing customizable prototype by using BIM platform would be formulated considering the local context: the context of labor-intensive construction system, in the context of rapid housing construction and in the context of traditional 2D based AEC industry. This context will be reflected on the design decisions to be made when designing the alternatives.

1.2.3.2 Specific objectives

- To identify some of the forces which are demanding customization in the 40/60 housing neighborhoods to use them as a show-case for developing customizable parts responding to such forces
- To identify which parts of the 40/60 housing could be customized to respond to the forces selected within the context of labor-intensive construction system
- To design and model, using BIM platform, alternatives to the identified customizable parts
- To generate a customizable prototype by combining the different alternatives in a BIM platform.
- To show exemplary neighborhood design in one of the 40/60 sites of Addis Ababa by using the customizable prototype developed.

1.3 Scope and Limitations

This thesis is limited to developing and testing a method of enriching the design 40/60 housing prototype with inbuilt customizable parts using BIM platform. It is not aimed at exploring the already proven potentials of BIM in the design stage. Due to the time limitation, and envisioned scope of the work, the different customization design options proposed are not meant to be the most responsive; rather they are used as a methodological input to explore design customization in a BIM platform.

1.4 Significance and Relevance of the Study

The first target group would be the end users of the housing program. The consulting and construction firms of Ethiopia participating in the program are also target groups. Design and construction professionals of Ethiopia working in the traditional fragmented approach are also another target groups.

The introduction of Building Information Modeling technology to the local AEC industry would have positive impact on cost, time and quality. Mass customization in housing would bring about environmental responsiveness, customer satisfaction and better city image. This research could have policy impact on the way mass housing prototypes are approached and designed.

1.5 Thesis overview

In the first chapter historical background on mass production and mass customization in housing is given. The current state of Housing in Ethiopia is also briefly described. The concept of Building information modeling is also introduced. The statement of the problem, research question, the general and specific research objectives are also included in this chapter.

The research methodology used for conducting this research is discussed in chapter two. The data sources, the data collection and analysis are described in this chapter. The reason why the methodology employed is specifically used for this research is also described in the introduction of this chapter.

Literature review and contextual review are given on the third and the forth chapters respectively. Literatures on the issue of mass customization in housing; Historical back ground and summary of different approaches and current trends in mass customization of housing is also given. Literatures on building information modeling, on its history, why the concept started, the advantages and challenges of implementation are revised. Detailed comparison of the 2D based approach and BIM approach is also described. The integrated housing development program of Ethiopia, its background, achievements and future plans by the government are also summarized in chapter four.

On the last chapter the proposal design process, results, conclusion and recommendations are given.

2 Research Methodology

2.1 Introduction

The research focuses on a contextual application of a technology, Building Information Modeling, to aid in solving a pragmatic problem-the problem of cookie-cutter prototypical approach in mass housing in developing AEC industry. The research will highlight on some of the problems caused by the cookie-cutter prototypical approach in the 40/60 housing based on analysis of the existing prototype and neighborhood designs. The research will focus on application of a technology to facilitate the process of solving the problem. The results of this research could be applied for other typological mass construction provided that it is in the same context - the context of rapid, labor-based and mass construction using few design typologies. To this end, design-based, experimental methodology is chosen to conduct the research.

To get to the answer to the research question: How could Information Modeling (BIM) technology assist in enriching the 40/60 housing prototype design of Addis Ababa with inbuilt customizable parts considering the current local context of traditional-2D based, rapid and labor-intensive construction system? , the following steps will be taken.

First, some forces that demand customization from the building prototypes are identified based on analysis of the current prototype design and neighborhood designs. Second, the parts of the 40/60 prototype that could be customized will be selected based on the forces identified considering the local construction context. Thirdly, alternatives will be designed for the selected parts of the prototype in Revit Architecture BIM platform responding to the forces identified (Revit is the most commonly used BIM software and it is purpose built for BIM(Eastman, 2011)). Finally a customizable prototype will be developed and exemplary neighborhood design will be done by applying the developed customizable prototype.

2.2 Data sources and data collection

A combination of primary and secondary data sources, triangulation, would be used for conducting the research.

2.2.1 Primary data sources

The primary data sources are used mainly through interviews of officials and professionals involved in the IHDP and the AEC industry at large.

2.2.1.1 Interviews

The interviews would aim at getting the background, current state, underline problems, achievements and future plans regarding IHDP, with a focus on 40/60 program. Regarding the trends of the AEC sector of Ethiopia, interviews would be conducted with respective officials from the Ethiopian Construction Project Management Institute. The method of interview is used because finding publications or up to date websites of government plans and reports appeared very difficult in Ethiopia.

2.2.1.2 Observations

Observations would also be made to the 40/60 construction site visits for getting a general primary outlook of the construction process. However, secondary data sources will be used for in-depth analysis because of the relatively short time available for the research.

2.2.2 Secondary data sources

2.2.2.1 Documents

Planning, design and construction documents regarding the 40/60 projects will be collected from consulting firms and Addis Ababa City Administration Saving Housing Development Enterprise. Policies, strategies, programs, reports and plans regarding the IHDP will be collected from Ministry of Housing and Urban Development of Ethiopia. Collecting the documents directly from the responsible offices is chosen because most of the documents are not publicized or not found in the official websites.

2.2.2.2 Literature review

Literature reviews focusing on mass housing and mass customization of housing in different contexts will be done. In addition, literatures on Building Information Modeling regarding the history, advantages and limitations, challenges of implementation etc. will be reviewed. Literatures focusing on the achievements and drawbacks of the IHDP of Ethiopia will also be briefly reviewed.

2.3 Data analysis

Literature-based, professional and on-desk data analysis method will be employed instead of primary on-site analysis for two reasons. Firstly, with the relatively short time available, it will not be possible to analyze enough samples of specific sites, needs from specific people. Secondly, since the research focuses on application of a technology, the results from the on-desk analysis should be applicable for different scenarios than the ones addressed in this paper such as material, color and texture customization.

For example, if a method is developed for varying a prototype in response to solar orientation, the same method can be applied to vary the prototype based on inhabitants' demand. Yet, while the design of variation based on solar orientation could be done based on literature and professional judgment, the variation based on inhabitants need demands intense interviews from each inhabitant which is time taking. But the method of how to achieve the variations is similar for both cases, and this method is the main focus of the research.

3 Literature Review

3.1 Mass customization in housing

3.1.1 Standardization in mass housing

Design standardization is about creating few typologies followed by large scale repetition of these typologies within one site or at different sites. Jaillon & Poon (2009) describe the two reasons why designs are standardization in mass housing in general. Firstly, it comes from the difficulty of getting and analyzing all the information from each site and the need of each user. The second reason is more related to the construction system. The argument is producing the same item repeatedly increases efficiency and intern reduces cost, which is the major goal of mass housing.

In 1920s, the first standardized housings that used industrial mass production were introduced. The Torten housing development by Walter Gropius in Germany and Pessac by Le Corbusier were the two prominent examples. The strategy was to design a limited number of typologies which will be prefabricated and repeated on a large scale (Jaillon & Poon, 2009).

However, standardization and mass production in housing was extensively used after Second World War. It was used to reconstruct the destroyed cities in Europe and also to house the huge returning army in the US. Nonetheless, the architecture resulting from mass production was restlessly repetitive without options and variations. The excessive monotony resulting from mass production led to the invention of new systems that would allow diversity. (Jaillon & Poon, 2009)(Dye, 2004)

One of the early critics of standardization of public housing Davis (1997) argues the idea that Standardization and replication of buildings is the best way to lower housing costs is partly a myth.

> ***It is true that standardization can produce efficiency but the cookie-cutter approach to housing is what has doomed so many public housing projects. The key is to find means including architectural variety and diversity within recurring building systems.***(Davis, 1997 pp 4)

Despite the fact that standardization increases efficiency, there is a need to find a way of adding variety resulting from different forces of a site. And this should not compromise the efficiency of the system.

3.1.2 Diversity and site specificity in mass housing, current trends

Currently, two trends can be seen on the way mass housing is approached to bring about diversity and site specificity, in general. The first approach is about creating non-standard specific designs for every site. This is mainly applicable for mid to high rise housing towers. The Hong Kong housing authority has recently moved to non-standard housing design. The authority claimed that non-standard designs helped them achieve better cost effectiveness, overcome different site constraints and enabled the utilization of land resources efficiently (Hong Kong Housing Authority, 2011). In spite of the advantages of the non-standard design approach, it is hardly applicable where there is a need for large scale housing which otherwise would take considerable time and effort to design each building separately.

The second and more varied approach in trying to create diverse and site specific housing, which is referred to as mass customization. Mass customization is about the creation of diverse elements at the cost and efficiency of mass production. This was possible due to the technological advancements in the design and production systems. The diverse elements are designed in advanced software and are directly produced by computer controlled fabrication systems (Dye, 2004). After analyzing the technology applied, for developing countries where the construction sector has not advanced much, complete mass customization of the mass housing would be faced with difficult challenges.

Arch & Israel (2013) describe the three developments that led to mass customization in the Architecture, engineering and construction industry: Building Information Modeling (BIM); the implications of programing in graphical representation, and the progress of computer-controlled manufacturing machines.

3.1.3 Mass customization and architecture

Technological developments in history have played a significant role in promoting new styles in architecture and shaping our built environment. Technological advancements have enabled innovative constructions methods and materials as well as provided new representation tools for architecture. (Fethi & Fine, 2014)

The fact that the modern movement in architecture was highly influenced by the Industrial Revolution is the most vivid example of technological development in architecture. Architects such as Le Corbusier, Walter Gropius and Mies van der Rohe experimented with architecture that could accommodate the new programs of the emerging industrialized era. (Fethi & Fine, 2014)

The design of mass housing in industrial age has been a pre-occupation in realm of architecture since the onset of the industrial revolution. Architects attempted to solve the housing shortage using the advantages of the industrial revolution by introducing a production process based on the assembly line. The assembly line, which was initially developed for the automobile industry by Henry Ford, became a paradigm for the housing industry. (José Pinto Duarte, 2001)

With the development of digital technology and the emergence of computer controlled manufacturing machines such as CNC machines, laser cutters, water-jets etc. during 1990s, the notion of mass-customization was born. Mass customization uses computer- controlled manufacturing machines to produce a large number of elements which were completely different from each other, while striving to take the same cost and time of mass production. Architects such as Greg Lynn, Mark Goulthorpe and Lars Spuybroek are the prominent examples that experimented and are experimenting with mass customization. (Fethi & Fine, 2014)

3.1.4 Models of Mass customization in housing

Different models are being experimented to bring about mass customization of housing. Here is a summary of some of the approaches:

3.1.4.1 Theory of supports

Habraken's theory of supports (1972) was one of the early attempts to bring about customization in mass housing. The theory distinguished between ‘support’ and ‘infill’ parts of the housing. The ‘support’ refers to parts like structure and infrastructure that the dwellers agree not to change throughout the life of the building. The parts of the building the dwellers can adapt to their needs are referred ‘infill’. (Habraken, 1972) (Benrós, Duarte, & Branco, 2007) After the application of the theory of Supports in different mass housing projects, the need for digital design tool to explore different designs based on client needs was underlined. (Fethi & Fine, 2014)

3.1.4.2 The ABC system

The Spanish architect Manuel Gausa developed a system, called ABC system, for customizing housing layout. ABC refers to closet, bathroom, and kitchen (Armario, Baño and Cocina in Spanish). Different layouts are generated by the placement of the three units based on predefined rules on a column free floor area. Heterogeneous façade is developed based on the various floor layouts. (Benros & Duarte, 2009)

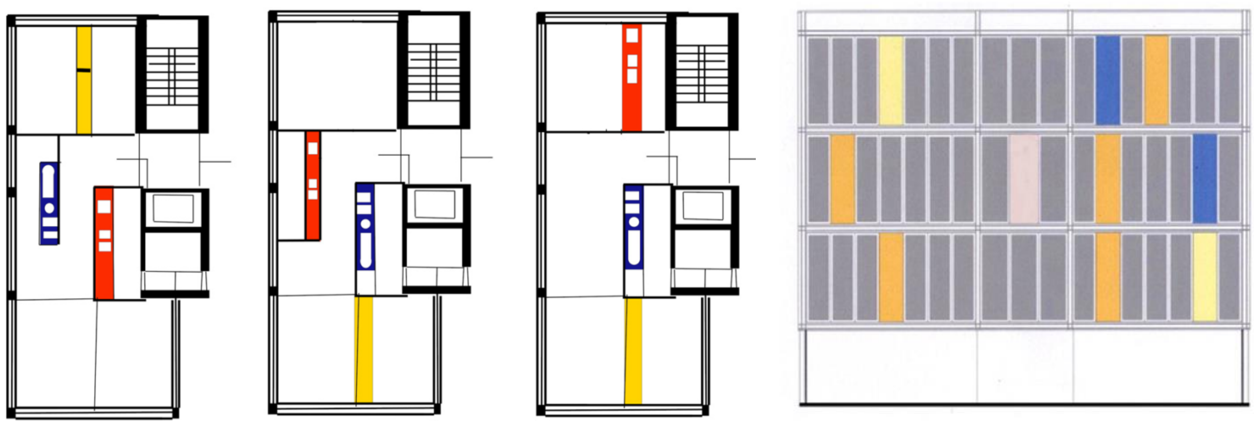


Figure 1: ABC system: Sample layouts (left) and façade (right) generated from the placement of closet, bathroom, and kitchen (*Armario, Baño and Cocina* in Spanish) source: (Benros & Duarte, 2009, pp 313)

3.1.4.3 Cellular Automata (CA) approach

Cellular Automata (CA) is one of the rapidly evolving digital design approaches with customization potentials. (Fethi & Fine, 2014) CA approach is based on rules of relationships in a programming environment. CA approach in mass housing was exemplified by a model developed with a potential of customer participation and choice. The model was developed by scripts of 3DS Max software. The interface allowed uses to participate in the layouts of the floor, which in turn generates the façade design. The site organization of the housing blocks the setbacks; façade design; floor layouts and spatial relationships of different units are generated based on CA rules. (Fethi & Fine, 2014)

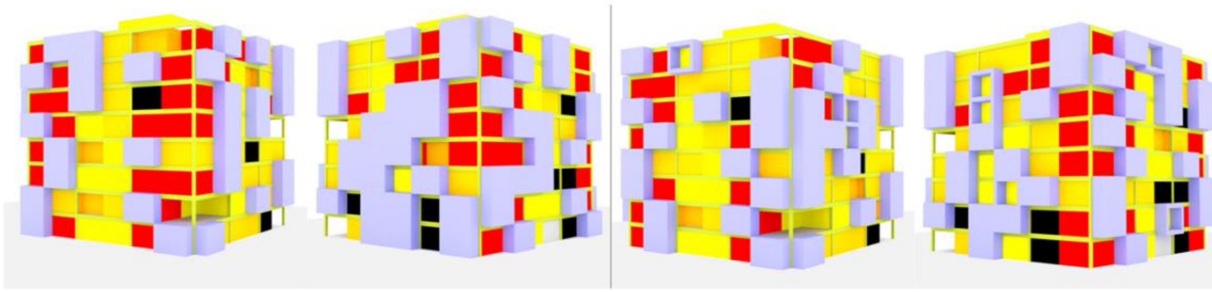


Figure 2: Different layouts and facades generated based on CA rules of relationships (source, Fethi & Fine, 2014 pp 364)

3.1.4.4 Housing Agency Systems (HAS)

Another housing customization approach based on algorithmic design and taxonomy was developed in USA. The approach, called Housing Agency Systems (HAS), would allow customers to actively participate in the design of their houses. The idea was initiated to help customers who can't afford to hire architects for the design of their houses. The interface allows customers to virtually communicate their needs with professionals in a web based environment. (Bergin & Steinfeld, 2012)

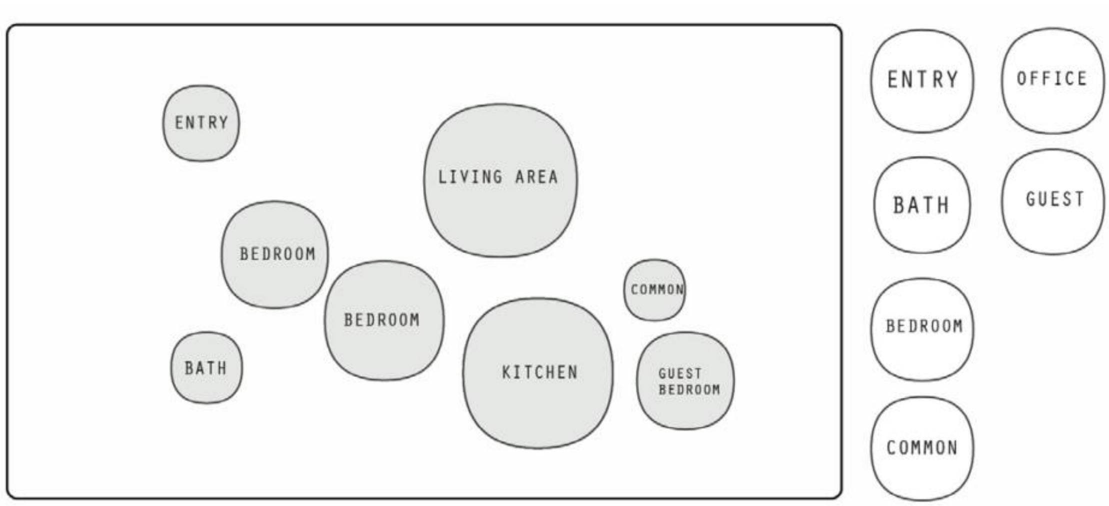


Figure 3: the HAS system allowed customers to drag and drop programmatic units in to the home; size the units relatively and define the relationships based on their needs. (source: Bergin & Steinfeld, 2012 Pp 97)

3.1.4.5 Discursive grammar approach

Mass housing customization strategy based on discursive grammar was experimented for Siza's houses at Malagueira. Discursive grammar is a combination of programming and designing grammar. While the programming grammar generates design brief based on client needs, the designing grammar provides rules based on the design brief to bring about design options satisfying the client needs. The programming grammar allows clients to fill the information they would normally give an architect during design brief. Information like family status, number of residents, layout preferences, parking conditions etc. will be filled in a web based interface. After that, design is generated by the designing grammar to match the client needs. If the client changes some of the requirements the design will also be automatically updated. (J.P. Duarte, 2005)

3.1.4.6 Modular prefabrication approach

Modular prefabrication approach experiments on mass customization of housing based on modular components available in the market. Customer needs are collected in a web based platform to generate designs from available modular components that suit the requirements. The proponents of this approach experiment on providing mass customized housing based on computer-aided design and a web-based modular component configuration system. (Huang & Krawczyk, 2006)

3.1.4.7 Finishing information system (FIS)

Finishing Information systems (FIS) gives a unique focus to mass customization in housing. It started up by the fact that most of mass customization approaches in housing focus mainly on plan layouts. FIS focuses on mass customization of finishing materials that allow the customers to express their personality and, thus, are the one of the most influential components of customer satisfaction(Shin et al., 2008)

3.1.5 Conclusion

From the reviews above, it is clear that mass housing is heading in the direction of mass customization. There is a clear focus on customer satisfaction through customization of housing. Efficiency is addressed though mass customization. The other common feature that can be observed is that the use of high-tech computerized production system of construction components as well as client need data gathering systems.

In the current system of the IHDP of Ethiopia, the exact end users of each unit are known only after the completion of the construction. For this reason and the reason of research scope, the customization concept employed in this thesis would focus on site specificity and external factors like monotony that could be addressed by professional judgment without requiring the input from end users. The customization would also be on the scope of labor-intensive construction system employed for IHDP of Ethiopia.

3.2 Building Information Modeling

3.2.1 Background

Building Information Modeling "BIM" is a relatively new approach in the whole Architecture, Engineering and Construction industry. It changes the way buildings are designed, communicated and constructed. "A BIM is a digital representation of physical and functional characteristics of a facility" (NIBS, 2015). Eastman (2011) defines BIM as "a new approach to design, construction, and facility management in which a digital representation of the building process is used to facilitate the exchange and interoperability of information in digital format. "

Building Information Modeling "BIM" is becoming a better known established collaboration process in the Architecture, Engineering and Construction "AEC" industry. Most of the world's leading AEC firms have left the traditional 2D Computer Aided Drafting CAD technologies and are using BIM for nearly all of their projects. The transformation came due to the proved benefits of BIM from pre-design, through the design/construction and post construction phases. (Eastman, 2011)

3.2.2 Why BIM

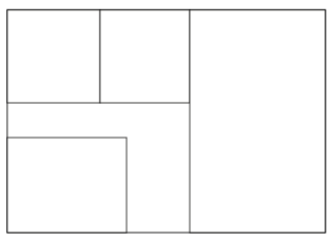
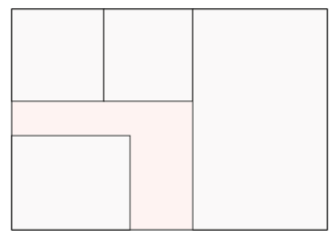
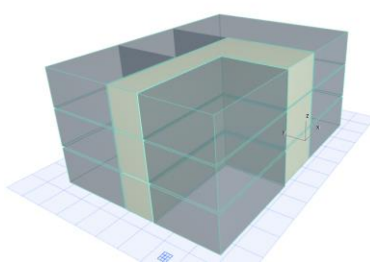
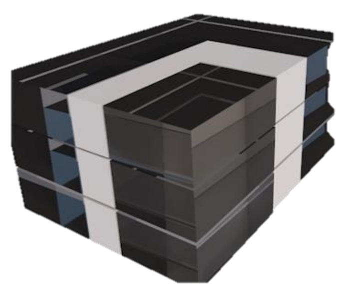
The concept of BIM was incepted because of the recorded inefficiencies in the fragmented traditional system of designing, constructing and managing buildings. The traditional CAD based 2D approach is known to cause unnecessary waste and errors in the design and construction of buildings. Poor field productivity, poor information flow, redundancy, imprecise quantity and cost estimation, inadequate interoperability are some of the problems associated with the traditional approach. (Eastman, 2011)

But the BIM delivery approach gives a seamless exchange, integration & management of project information which in turn results in improvements in terms of program, productivity and quality. According to a study Stanford University Center for Integrated Facilities Engineering (CIFE) based on 32 major projects using BIM there was a 40% elimination of unbudgeted change; cost estimation accuracy within 3% at 80% reduction in time taken to generate it; savings of up to 10% of the contract value through clash detections and up to 7% reduction in project time were registered.

3.2.3 Comparison of the Traditional Approach and BIM Approach in the Architectural Design Stage

The following tables would give a graphical summary of comparison of the traditional approach and BIM approach in the architectural design stage as extracted from Eastman (2011).

Schematic design

	Traditional Approach	BIM Approach
Program And Space Layout	Prone to discrepancy between program area and conceptual design ¡ Manual space area calculation ¡	Conceptual design based on program area ¡ Automatic space area generation ¡
	 **Figure 4: traditional layout: simple Set of lines**	 **Figure 5: BIM layout (automatic areas, zones …)**
Mass Modeling	Only visual model ¡	Visual as well as data rich model ¡ Better cost estimate ¡
	 **Figure 6: Traditional mass model**	 **Figure 7: BIM mass model**
Design Option Development And Comparison	Manual space layout options development ¡ Manual comparison (prone to errors and time taking) ¡	Automatic space layout options development ¡ Automatic comparision between the design options and original program (faster and accurate) ¡

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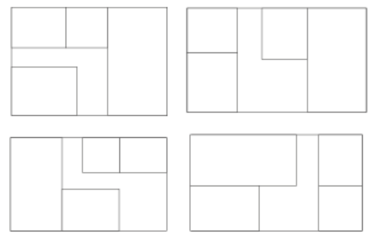
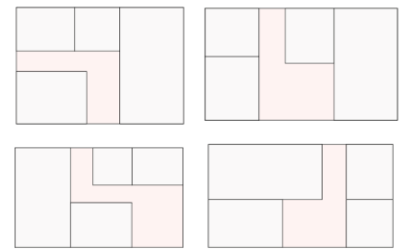
<td>
Figure 8: Traditional options developemet</td>
<td>
Figure 9: BIM options development</td>
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<tr>
<td>Design Assessment And Evaluation</td>
<td>Manual comparison (prone to errors and it is time taking) ¡</td>
<td>Automatic comparison between design (design options) in reference to original program (faster and accurate) ¡</td>
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<table>
<tr><th></th><th>Option 1</th><th>Option 2</th><th>Option 3</th><th>Option 4</th></tr>
<tr><td>Room1</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Room2</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Room3</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Room4</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Corridor</td><td></td><td></td><td></td><td></td></tr>
</table>
Table 1: Automatic comparison (area, volume . . .)
</td>
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<tr>
<td>Schematic Cost Estimate</td>
<td>Very generic cost estimate usually based on total floor area ¡</td>
<td>Specific to project cost estimate based on information provided ¡</td>
</tr>
</table>

Table 2: Comparison of Traditional and BIM approaches; Schematic Design

Preliminary and Final Design

	Traditional Approach	**BIM Approach**
Building Elements	▪ Wall, slab, window, door ...are just representations ▪ They are redundant in plan /section/elevation ... ▪ Does not understand relationships between building elements	▪ Wall, slab, window, door ...contain data like material, dimensions, position ... ▪ Single model (non-redundant) ▪ Understands relationships between building elements

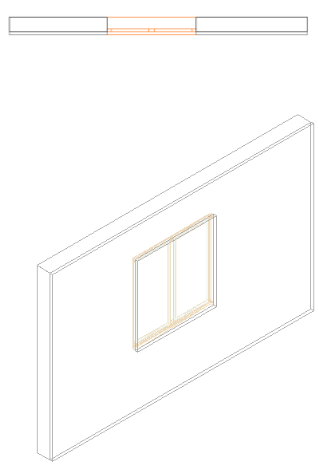
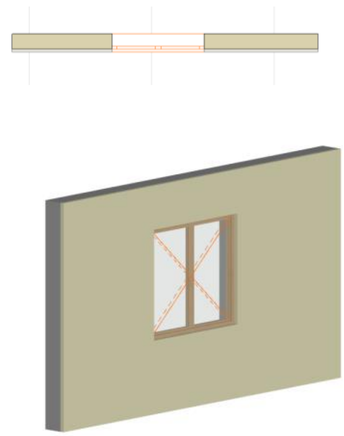
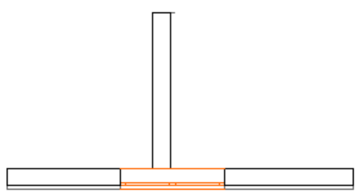
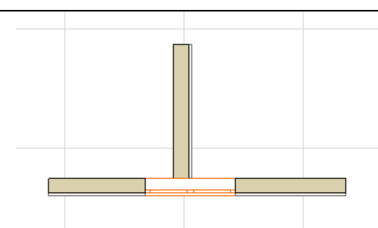
	 Figure 10: traditional 3D (set of lines): redundant	 Figure 11: BIM 3D (wall, plastering, glaring, and frame)-Coordinated
Design Errors and Warnings	▪ Design Errors need manual checking	▪ Automatic identification of design errors and warnings are given
	 Figure 12: Error in traditional model	 Figure 13: Automatic error warning in BIM
Building Systems	▪ New models for structural, acoustic, lighting, sustainability…analysis.	▪ Data rich model for structural, acoustic, lighting, sustainability…analysis.

Table 3: Comparison of Traditional and BIM approaches; Preliminary and final Design

Data generation and Drawing Production

	Traditional Approach	BIM Approach
Data Sheets	▪ Manual production of space data	▪ Automatic generation of space data

<table>
<tr><td></td><td></td><td><table><tr><th></th><th>Room 1</th><th>Room 2</th></tr><tr><td>Area</td><td></td><td></td></tr><tr><td>Perimeter</td><td></td><td></td></tr><tr><td>Windows</td><td></td><td></td></tr><tr><td>Doors</td><td></td><td></td></tr><tr><td>Volume</td><td></td><td></td></tr><tr><td>...</td><td></td><td></td></tr></table>Table 4: Room data sheet in BIM</td></tr>
<tr><td>Bill of Quantities</td><td>▪ Bill of quantities done manually (prone to errors and slow)</td><td>▪ Automatic generation of bill of quantities (accurate and fast)</td></tr>
<tr><td>Cost Estimation</td><td>▪ Manual</td><td>▪ Automatic based on inserted database</td></tr>
<tr><td>Drawing Production</td><td>▪ Manual and redundant</td><td>▪ Non-redundant automatic generation</td></tr>
</table>

Table 5: Comparison of Traditional and BIM approaches; Data generation and Drawing Production

3.2.4 4D and 5D BIM

"4D models and tools were initially developed in the late 1980s by large organizations involved in constructing complex infrastructure, power and process projects in which schedule delays or errors impacted cost. As the AEC industry adopted 3D tools, construction organizations built manual 4D models and combined snapshots of each phase or period of time in the project. Custom and commercial tools evolved in the mid- to late 1990s, facilitating the process by manually creating 4D models with automatic links to 3D geometry, entities, or groups of entities for construction activities. BIM allows schedulers to create, review, and edit 4D models more frequently, which have led to the implementation of better and more reliable schedules." (Eatman, 2011)

4D BIM: a 3D model linked to time or scheduling data. Model objects and elements with this data attached can be used for construction scheduling analysis and management. 4D BIM can also be used to create animations of project construction processes.

5D BIM: usually a 4D BIM linked to cost data. The time data adds another dimension to cost data, allowing expenditure to be mapped against the project program for cash flow analysis, etc. (Branz, 2014)

The manual process is typically done within an available CAD, BIM, or visualization software. Specialized 4D software eliminates some steps, and provides direct links to the schedule and building model thus making the process faster and more reliable.

Relevance of 4D and 5D BIM for the housing process IHDP

Before construction

- Accurate quantity takeoffs
- Scheduling and schedule changes

During construction

- Tracking construction process
- Tracking Project status and reporting
- Phasing
- Sub-contractors (specialized contractors) involvement stage
- Prefabrication
- Form work / temporary components
- Material order and procurement purchasing
- Tracking variances between budget and actual cost

After construction

- Maintenance and facility management,
- Owners registration

3.2.5 The current AEC business models and BIM

Eastman (2011) describes four approaches in the current AEC business in relation to their level of applicability for BIM.

3.2.5.1 DBB: Design Bid Build

In DBB model the client first comes to an architect with an idea to be developed to design brief and program. The architect then goes through stages of design from schematic to preliminary and then final design. Other building professionals like MEP, HVAC, quantity surveyors etc. would be involved under the architect.

After the design is completed, a tender document will be prepared and bid will be floated. A contractor will be selected based on price offered and technical capacity. Sub-contractors will be selected by the contractor with the same process.

The construction process begins after the completion of the design and the bidding stage. After completing the construction as-built drawings are done and the building will be handed over to the client. (Eastman, 2011)(The typical DBB process mentioned above could vary depending on specific projects)

In DBB practice Inconsistency, inaccuracy, and uncertainty in design are common and often lead to disputes with the contractor, as errors and omissions are detected and responsibility and extra costs reallocated. Numerous changes are made to the design as a result of previously unknown errors and omissions, unanticipated site conditions, changes in material availabilities, questions about the design, new client requirements, and new technologies.(Eastman, 2011)

For these reasons, DBB business model is the least favorable to bring about BIM in the AEC industry. The DBB approach presents the greatest challenge to the use of BIM because the contractor does not participate in the design process and thus must build a new building model after design is completed.(Eastman, 2011)

3.2.5.2 DB: Design Build

In the DB model the client hires a single body for both design and construction. Though competiveness is reduced in this business model, the building process will be faster and with little financial changes if designs are not changed. (Eastman, 2011)

For the reason that design and construction are headed by a single entity, DB creates favorable opportunity for the application of BIM technology when compared with DBB. The DB approach may provide an excellent opportunity to exploit BIM technology, because a single entity is responsible for design and construction. (Eastman, 2011)

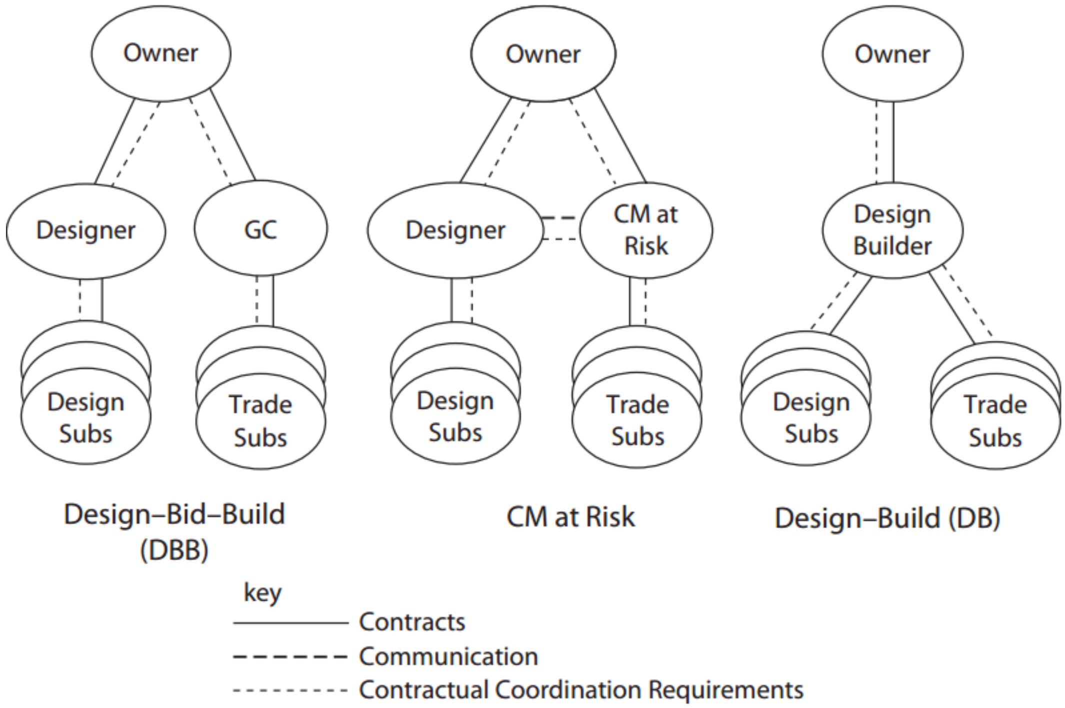


Figure 14: Schematic diagram of Design-Bid-Build, CM at Risk, and Design-Build processes.(source: (Eastman, 2011pp 4)

3.2.5.3 CM@R: Construction Management at Risk

CM@R business model is a method in which an owner retains a designer and a construction manager to furnish design services and also to provide construction management services respectively. The designer and the project manager stay on the project throughout the preconstruction and construction phases. (Eastman, 2011)

The cost of the project is guaranteed (guaranteed maximum price or GMP) by the construction manager (usually a licensed general contractor). The owner is responsible for the design before a GMP can be set. (Eastman, 2011)

Unlike DBB, CM@R brings the constructor into the design process at a stage where they can have definitive input. For this reason, CM@R increases the benefit of using BIM and other coordination tools.

3.2.5.4 IPD: Integrated Project Delivery

The distinguishing feature of IPD is the effective collaboration among the owner, the designers, and the contractor(s). The collaboration starts from early conception of the project until the handover through the construction. The key concept is that this project team works together using the best collaborative tools at their disposal to ensure that the project will meet owner requirements at significantly reduced time and cost. (Eastman, 2011)

BIM and IPD go together. They represent a break through from the current fragmented linear processes that are based on paper representation exchange of information.(Eastman, 2011)

3.2.6 Challenges of implementation of BIM

Although the advantages of using BIM over the traditional delivery system are very clear, there are many obstacles to implementation. Contractual and legal requirements different from the traditional approach; existing conditions of contract and legal practice are some of the obstacles from the legal side. The technical aspects of BIM like Implementation costs, the need for education and training, advanced software and hardware requirements are also major obstacles to implementation. Changing the established business processes where allocation of risk and sharing of reward is clear to a new relatively communal system is also another major challenge to implementation. (Eastman, 2011)

3.2.7 BIM Practice of Hong Kong Housing Authority

Hong Kong housing Authority is a governmental statutory body that develops and implements a public housing program to meet the housing needs of people who cannot 'afford' private rental housing. Till 2013 the authority had 730,000 housing units under it with a plan of building about 100,000 for the next two consecutive five year periods. (Fung, 2013)

It is one of, if not the only, mass housing programs in the world that use BIM technology extensively. In 2013, they had planned to use BIM for all public housing projects in Hong Kong. (Fung, 2013)

The way mass housing is approached by the Hong Kong housing Authority has similar features like the IHDP of Ethiopia in its scale and way of management. For this reasons, a detailed study of the approach, challenges of implementation and lessons could help in starting BIM for the IHDP of Ethiopia.

3.2.8 Conclusion

As we have seen above, although the advantages of using BIM system are now a proved concept, there are obstacles to implementation. The obstacles would naturally be prominent in developing countries like Ethiopia where the standard of AEC industry is relatively low.

To introduce BIM to the country, starting with the INTEGRATED HOUSING DEVELOPMENT PROGRAM would be easier for many reasons. The fact that it is government led program makes the legal obstacles of implementation minimal. In the program, the same design is repeated over many sites with minor modifications. Therefore, the technical costs of implementation like advanced software and hardware costs will be distributed over hundreds of thousands of units which would make the cost increase minimal.

From IHDP, 40/60 housing was chosen for many reasons. First of all, being planned for middle income the 40/60 program is assumed that it is in better financial stand than 10/90 or 20/80 programs. Parallel to solving the housing deficit, the 40/60 housing is also planned to make the image of the city better through better visual design and quality finishing. 40/60 program would be easier to start with in this paper because it is a program on the start and no single house has been transferred until the time this paper is compiled which makes the analysis of all the sites and prototypes possible within the short timeframe of this thesis.

Architects were pioneers in using BIM. The MEP designers, fabricators as well as Builders follow the architects in using BIM. (Eastman, 2011) Therefore, starting the architectural design of INTEGRATED HOUSING DEVELOPMENT PROGRAM of Ethiopia BIM process would be the first step in bringing the system after the client interest. The government of Ethiopia has established The Ethiopian Project Management Institute with the aim of bringing BIM to the country starting with the housing and cluster offices. (Zahara, 2016)

4 Contextual Review

4.1 BIM in Ethiopia

Despite the fact that BIM technology is in its very early stage in Ethiopia, there are some significant moves to bring the technology. The Ethiopian Construction Project Management Institute (ECPMI) is responsible for transferring BIM technology in to the Architecture, Engineering and Construction sector (AEC) from the government side. Implementation strategy for BIM technology in the AEC sector of Ethiopia is also included in the yet not publicized Growth and Transformation Plan-II. There are also few private firms trying to utilize the technology in their respective expertise. (Zahara, 2016) (Fitshum, 2016)

An international bid Document has been prepared by ECPMI for supply, installation and training of Building Information Modeling (BIM). The bid aimed at securing hardware, software and BIM experts to train professionals from the AEC industry in Ethiopia (ECPMI, 2015). ECPMI has also conducted its first BIM workshop in Addis Ababa in 2015. In its three days, the workshop focused on introducing BIM to the major players of AEC sector in the country. Private and public consulting firms, construction companies as well as government representatives attended the workshop. (Zahra, 2016)

The plan of ECPMI is to bring about BIM technology transfer via giving Training of Trainers (ToT) for selected professionals from the local industry. The trained professionals then in turn train other professionals from the industry. The assumption is that the industry will accept the technology and would in turn have an impact in policy making. (Zahra, 2016)

4.2 Integrated Housing Development Program of Ethiopia

4.2.1 Background, achievements and future plans

Ethiopia is one of the least urbanized but rapidly urbanizing countries of the world. The UN estimated the 19% urban population of the country would triple between 2010 and 2040 urbanizing at a rate of 3.5%(CAHF, 2015). Despite this rapid rate of urbanization, there is a significant deficit in the housing stock of urban areas. According to UN-HABITAT slum definition, 80% of Addis Ababa, the capital city of Ethiopia, is slum. Out of the 80%, 70% is government owned rental housing (Un-Habitat, 2011). Only 30% of the housing stock in Addis Ababa is in fair condition while the remaining 70% needs total replacement or significant upgrading (CAHF, 2015). Rapid rate of urbanization coupled with poor quality housing stock resulted in a huge demand for housing(Un-Habitat, 2011).

In 2005, the Ethiopian government initiated an ambitious housing program called the Integrated Housing Development Program (IHDP). The IHDP was not initiated only to address the housing problem, but also to use the housing program as an instrument to create jobs, enhance the capacity of construction industry, and regenerate slum areas to mention some (Un-Habitat, 2011).

In five years, from 2005 to 2010, the IHDP transferred 171,000 housing units in different cities of the country, Addis Ababa taking the largest share. 78,000 housing units were constructed in Addis Ababa (CAHF, 2015). One of the most pressing challenges of the program was the issue affordability, which the program tried to address in its second phase.

A second phase of IHDP was launched in 2011 with the aim of providing housing based on income levels. The cheapest is called 10/90 where the saving 10% would guarantee 90% bank loan which will be paid after receiving the house unit. With the same principle, 20/80 and 40/60 programs are provided for home seekers with increasing income level. For those who can afford even more, housing cooperatives were another alternative in the second phase of the IHDP scheme.

In 2015, The Ministry of Urban Development, Housing & Construction (MoUDHC) announced its plan to build 2.45 million houses in the second Growth and Transformation Plan (GTP2) from 2015 to 2020 (the successor to the economic development program from 2010 to 2015). Out of the 2.45 million houses to be constructed, 750,000 will be in urban areas and 335,000 in Addis Ababa (Assefa, 2015) (Asrat, 2016).

4.2.2 Design standardization and the IHDP of Ethiopia

Overall, the same design strategy was used in all the housing projects. Design is primary set with few typologies and used throughout the different sites with minor modifications for site adaptation (Un-Habitat, 2011) (Kifle, 2008). The housing block designs are largely set and the neighborhood design is done specifically to each site through a competition.

The block typologies which were set initially were prone to series of modifications due to different forces. One typology, for example, was modified to six different versions. The modification was done only through changing the way the block was partitioned (Kifle, 2008). Recently we have seen a major modification in the 40/60 housing scheme while under construction to accommodate more units. The original six apartment units per floor were changed to 10 per floor without increasing the overall area (Zerihun, 2016).

It’s hard to say that the minor modifications of the typologies to adapt to specific sites were successful. We have seen cases where two floors of a building were totally below the natural ground level due to the steep slope of the site (Kifle, 2008). Whether the housing block faces the harsh southwest sun or a very chaotic street, the treatment and the arrangement of the façade remained the same. The minimal consideration of site specificity and variety has resulted in monotonous neighborhoods.

4.2.3 Construction system of IHDP

The construction system of IHDP is an extracted from the principles of reconstruction in the post war Germany. It uses low cost housing (LCH) technique with concrete pillar and slab system(Cherenet & Sewnet, 2012)(Hebel, 2010). The use of construction machineries is minimal. Instead, labor intensive approach is used so as to create jobs through specialized Micro and Small Enterprises (MSE)(Un-Habitat, 2011).

Construction contractors are hired to build the structure of the blocks. Prefabricated construction materials like precast beams, hollow slab blocks and hollow concrete blocks are produced by SMEs. The finishing works (painting, plastering, tile works…), sanitary and electrical installations, site works and others are given to sub-contractors consisting of MSEs (GTZ, 2005).

4.3 Conclusion

With the speed at which the IHDP is being implemented, however the approach is praised or criticized, there is a need to act and work within the system to see better built environment. We cannot wait for alternative approaches no matter how good they are to act and add value to the IHDP, but those researches on alternative approaches should go parallel.

We also cannot wait for the AEC industry to advance significantly in technology to start thinking and improving the IHDP with what we already have. It is time to focus on what we can do within the system to deliver better houses for the owners and better buildings for the city. If we choose to wait for alternative approaches or technological advancements to act on the IHDP, the previous progress tells us that the will be built as they are in huge quantities no matter what. Therefore, I call for more researches to be done in trying to improve the program, while in parallel, conducting researches looking for alternatives for solving the housing deficit.

5 Research/Design Process

5.1 Conceptual approach

Introduction

Although the research is more of technological in nature, there is a need for variables to experiment on the application of the technology in a specific context. The research is about the application of Building Information Modeling in designing customizable typologies. The typologies designed should somehow have the ability to vary in response to the different forces demanding diversity.

Step 1: Identifying force/forces that demand variation

The first step would be to identify the different forces that demand some kind of variation in the typologies. For instance, the façade may vary due to different solar orientations. The partition layout could vary based on the intended function. The issue of the forces that demands variation is described by Dye (2004) in his studio:

> ***How can a prototype be repetitive, yet differentiate as per all of the outside forces of site, homogeneity, globalization, cultural diversity, economics, climate etc.?...prototypes that were responsive and adaptive to different outside forces such as site, program, budget, climate, culture, time, speed homogeneity…*** (Dye, 2004 pp 217)

Step 2: Deciding which parts to vary and how to bring about the variation

Depending on different factors, some part of the typology may be set as 'rigid' that will not vary. However the 'infill' is the part of the typology that varies in response to different forces. Structure and infrastructure could, for example, be part of the 'supports' and the partitions and façade layout could fall in to the 'in-fills'. This is similar to the Theory of Supports developed by John Habraken (Benros & Duarte, 2009).

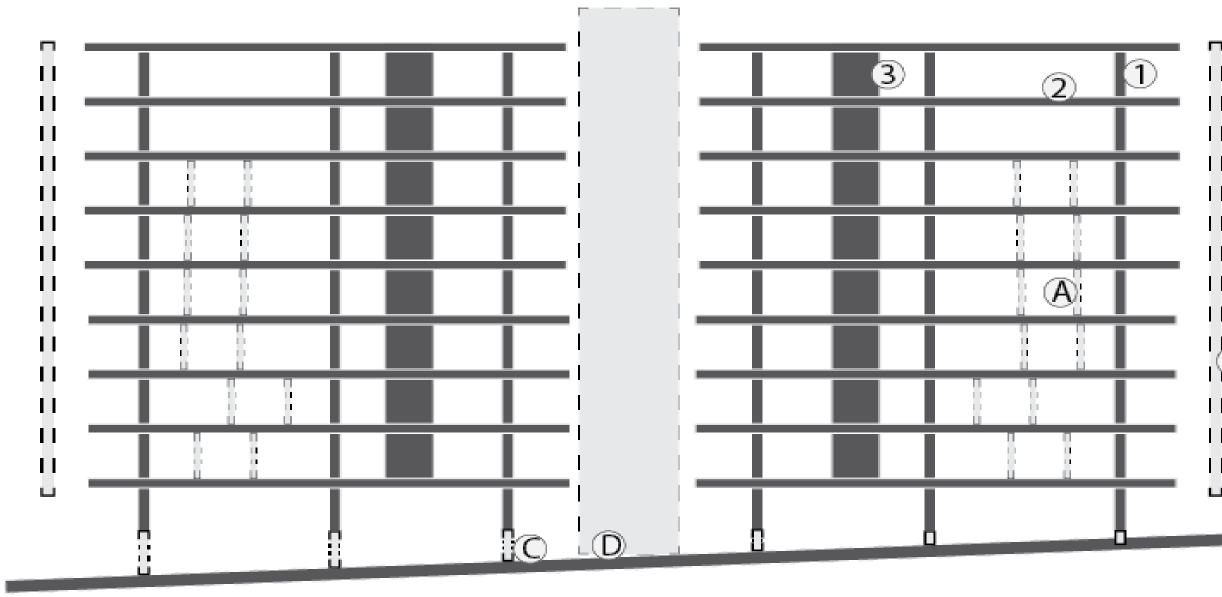


Figure 15: 'supports' and 'in-fills'. The columns (1), the slabs (2) and the wet cores (3) could be set as 'supports' and the partitions (A), the façade (B), the ground connection (C), the vertical circulation core (D) could be part of the 'in-fills'.

Step 3: Designing and modeling alternatives in BIM platform

Designing different options for the corresponding forces will be the next step. How should the façade be designed when facing the east or the west? How could the building respond when it is placed in chaotic, street as compared to a quiet residential neighborhood? These kind of questions would lead to the design of different alternatives for the 'in-fills' in response to the different forces.

Step 4: Combining the set of alternatives for a specific situation

The design alternatives are then modeled in the building Information Modeling Platform. This allows picking alternatives from multiple sets and generating a typology responding to the forces under consideration. The BIM would allow automatic generation of all construction documents of the customized typology.

5.2 Technical Approach

Revit Architecture will be used as a BIM platform for the modeling of the prototype. The options tool, groups and links will be used for customization options. The model would be developed in Revit with embedded options of variety. The main slab and columns will be set primary. Then, the façade, the partitions, the ground floor connection with the slab will have a set of options to choose from depending on the specific site context. So on the model, you can choose a façade for SW or E. you can choose to have shops in the ground or apartments. You can choose ground attachment based on the specific site slope. These are some options. After choosing all needed for one site, you can then generate all the drawings, documentation, schedule etc… for that specific site. You can also add additional options, for example a new façade layout, and embed it in the existing system.

The customizable prototype helps to make each block somewhat site specific. In addition it breaks the monotonous repletion of blocks without much effort; because of BIM technology (this is not possible with traditional 2D system). It is contextual as it can be done within the current construction technology in Ethiopia.

It is like a cocktail of building elements to choose from, and getting the final composed design with the help of BIM.

5.3 Step 1: Identifying force/forces that demand variation

5.3.1 Site slope conditions (Topography)

The site slope condition is one of the foremost forces for shaping the base of the building. The slope of the site will be critical in determining the drainage, entry exit, and basement position etc. of the prototype building. Architectural disaster has strike previous models / prototypes of IHDP built in Addis Ababa, Ethiopia because of the poor site adaptation design. (see figure below)

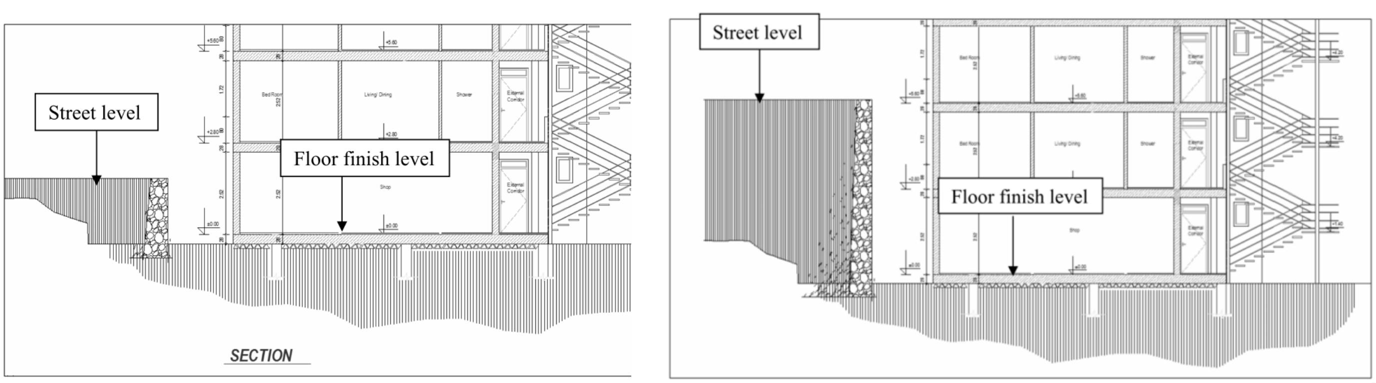


Figure 16 Section showing the street level with floor finish level of approximately 2m & 5.5 m (Kifle, 2008)

Taking the case of the Bole *Bulbula* site for the construction of the 40/60 housing scheme, one can see that the blocks are arranged on different site slopes with each their own steepness level. It is difficult, if not impossible to read any type of pattern arrangement influenced by the site slope.

Figure 17: varying topographic situations on Bulbula 40/60 neighborhood design

For the purpose of this research, I have developed the basic site slope scenarios (see figure next page) in which to put the 40/60 block. By identifying these basic positions, we can easily replicate their solutions to real life sites. Once the design alternatives are made for those basic scenarios, additional options could be developed for situations not falling on the listed options.

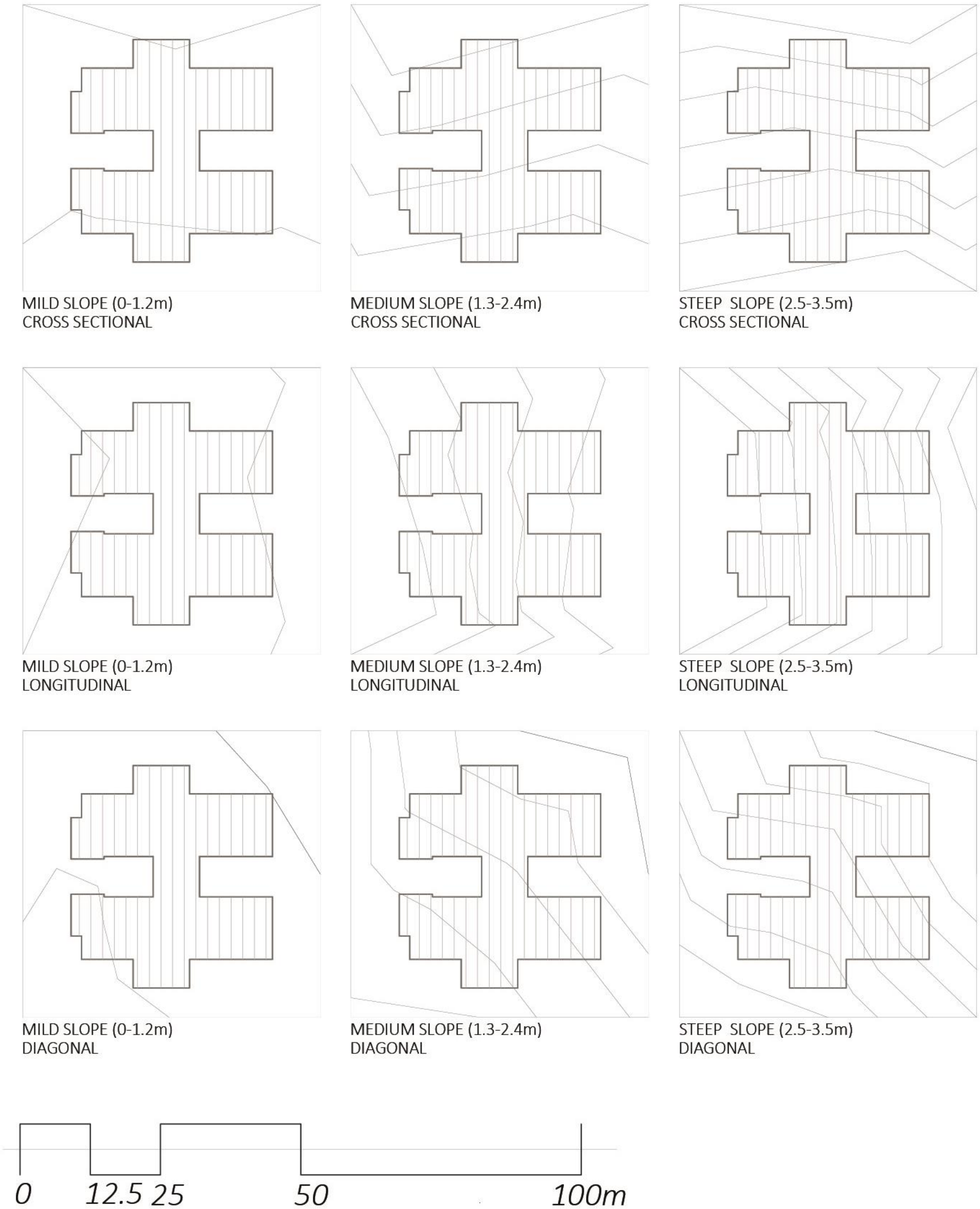


Figure 19 Possible ground floor senarios

5.3.2 Function of lower floors

The 40/60 housing scheme was first envisioned to be a city center housing program. As such according to its location and nearness to the central business district, many of its lower floors can be dedicated to small and medium sized commercial activities. There could be some cases in which 3 stories can be dedicated to shops/commerce and there could be blocks where only one story could be enough for the commercial needs of the neighborhood.

In another scenario, there could be many 40/60 building in one site in which the blocks facing the main or atrial streets could have higher commercial to housing ratio than the once found in the inner side of these blocks.

5.3.3 Building orientation (solar)

When the original 40/60 design was developed, there was little consideration to the building orientation because no one knew in what type/s of sites it was going to be constructed. One may find that even in one particular site, blocks could be arranged facing north- south or East- west or anything in between right next to each other. This proves that building orientation is of less importance in the arrangement of blocks. We can see the following examples to illustrate.

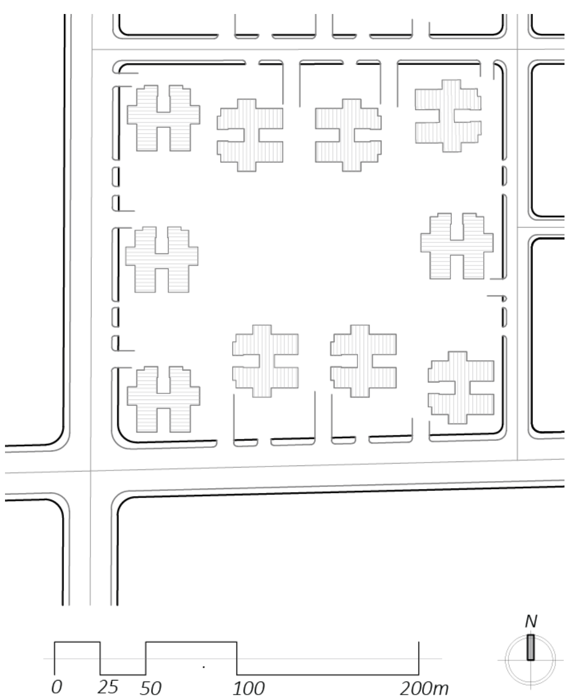


Figure 20 Part of Bole Ayat 2 – NHD plan

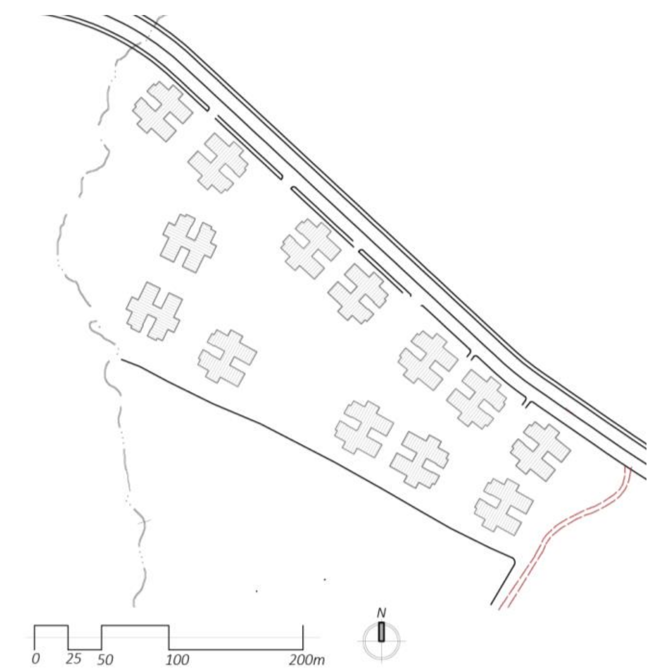


Figure 21: Asko Shekila – NHD plan

After observing the above, this thesis has categorized the different types of orientation into four major scenarios and has set angular range of tolerance in each category.

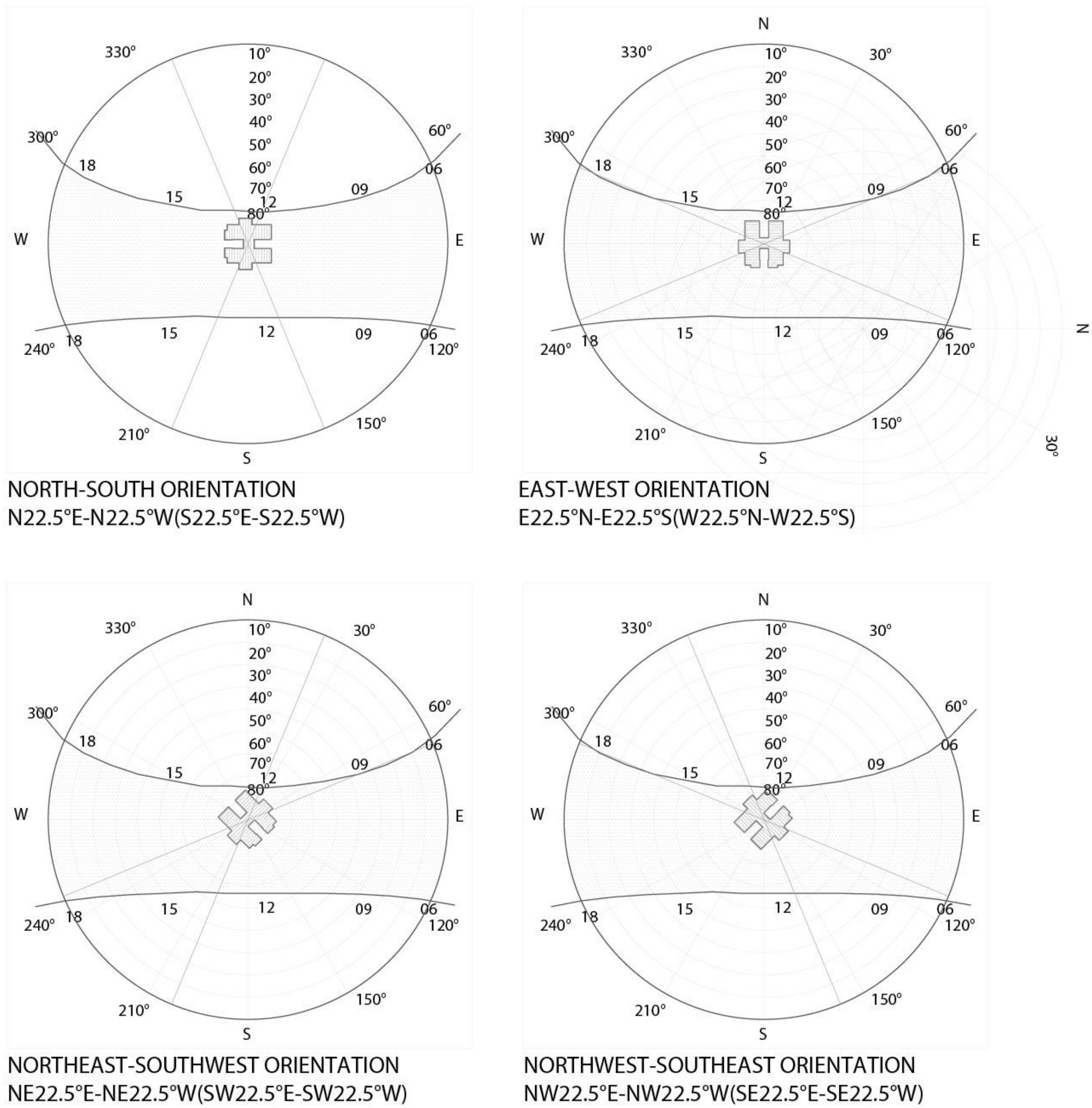


Figure 22 Possible solar orientation senarios

5.3.4 Visual Monotony

Human beings prefer ordered complexity and not randomness in their environment, a result of our perceptual system evolving to interpret natural forms. We know from observation that

human beings crave structured variation and complex spatial rhythms around them, but not randomness. Monotonous regularity is perceived as alien, with reactions ranging from boredom to alarm. (Salingaros, 2011 pp 3)

This could possibly be because one does not encounter large- scale geometrical configurations with a lot of monotonous repetition around his/her environment. In fact all such examples are not natural but man-made especially after the industrial times where mass production is the norm. Thus the human eye is negatively affected by Monotony since it is not an occurrence in nature or even pre-industrial times.

For the sake of this thesis dealing with the 40/60 housing project, I have tried to see Visual monotony in its ***Vertical*** and ***Horizontal*** expressions.

Vertical Monotony

The design of the 40/60 housing is vertically monotonous in that all floors have identical façade treatment, color and arrangement. Monotonous repetition of the accepted plan results in a monotonous elevation. Such design would lack the visual complexity and need of variation the human perceptual system craves.

Figure 23 Vertical Monotony – Elevations of 40/60 housing

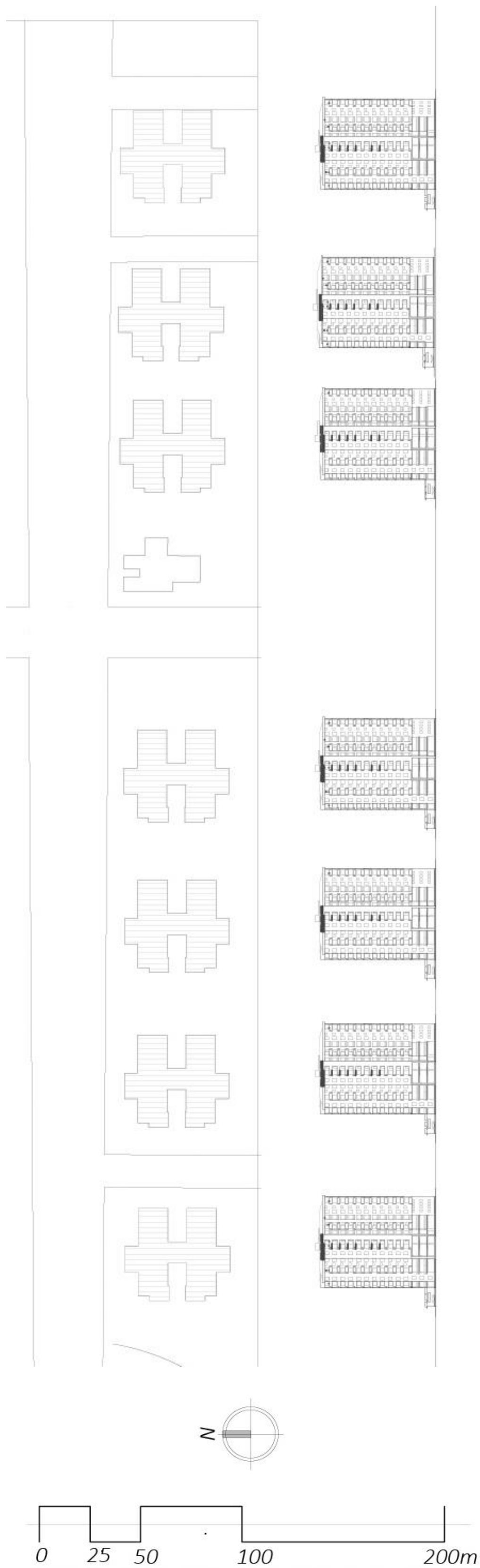


Figure 24 Part of Bulbula – NHD Plan: repetition of identical blocks

Horizontal Monotony

After Understanding vertical monotony, it is easy to imagine the repletion of these blocks numeral times in all directions along a street. One can see such example in the already built condominiums in Addis Ababa where you can have 100 plus identical building all in one super block only different from each other by their block number.

This can easily be prevented with simple modification of floor plans in addition to modification due to sun directions or site situations.

Another means is to design a variety of repeating modules in which to repeat with a particular pattern or arrangement. As stated earlier, although the human perception craves variety and complexity, it does not feed on randomness. Thus, the aim is not to create something wild, fancy & out of this world, the aim is to make designs look structured yet variable to the parameters of the natural and human factors.

Alternative designs given for each opening/balcony situation could be arranged in variety of ways based on professional judgment. This would allow the creation of variety for blocks facing the same orientation.

5.4 Step 2: Deciding which parts to vary and which parts to set constant

The main structural columns (excluding part of the ground floor columns), the circulation core (excluding the ground floor), the slabs (excluding the balcony slabs) and the roof structure are set as primary elements. The apartment partitions from the 3^{rd} to the 12^{th} level were also set primary. These structures will remain constant in all variations. They were chosen for the reasons of structure and simplicity.

The ground floor with its core is set to vary so as to adapt to the different slope conditions. The function of the 1^{st} and 2^{nd} floor is set to vary between residential and commercial based on location. The façade (including the balconies) are also set to vary based on solar orientation. To avoid excessive visual monotony, the façade layout within one orientation is also set to vary.

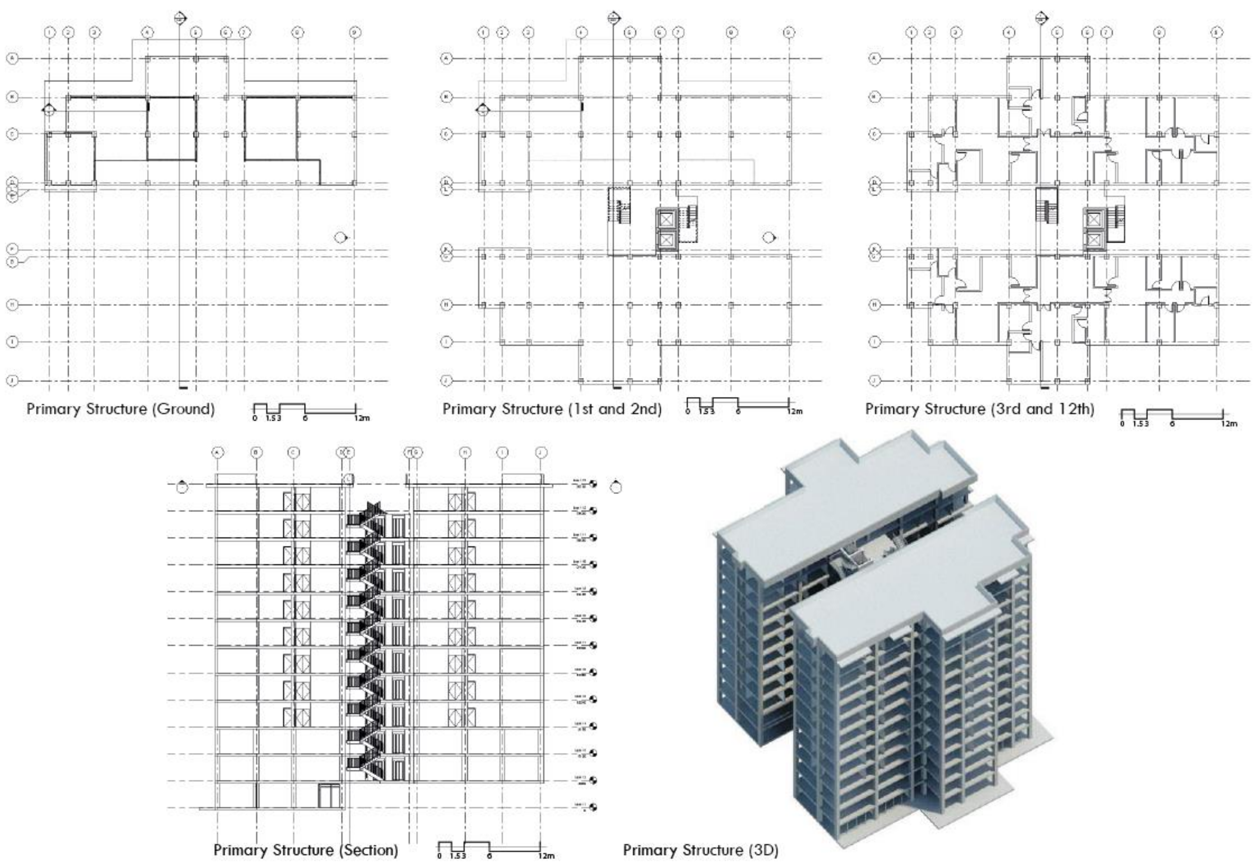


Figure 25: The primary structure in plan, section and 3D

5.5 Step 3: Designing and modeling alternatives in BIM platform

5.5.1 Site slope conditions

From the cross sectional, longitudinal and diagonal slope conditions the cross sectional is selected as a case and the alternatives are designed and modeled in Revit Architecture 2016. (Revit is the most commonly used BIM software and it is purpose built for BIM(Eastman, 2011)). MEP designs need to follow the architectural variations to make the modification complete. The different options would be chosen from the Revit model based on the slope conditions. The quantity and schedule variations for the different options could be compared easily as the model is data rich.

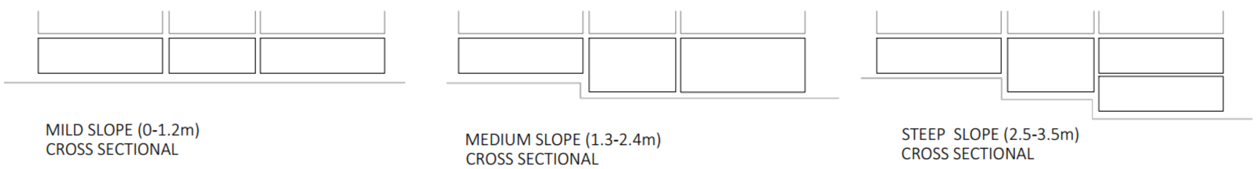


Figure 26: conceptual design solutions for different site slope conditions (cross sectional)

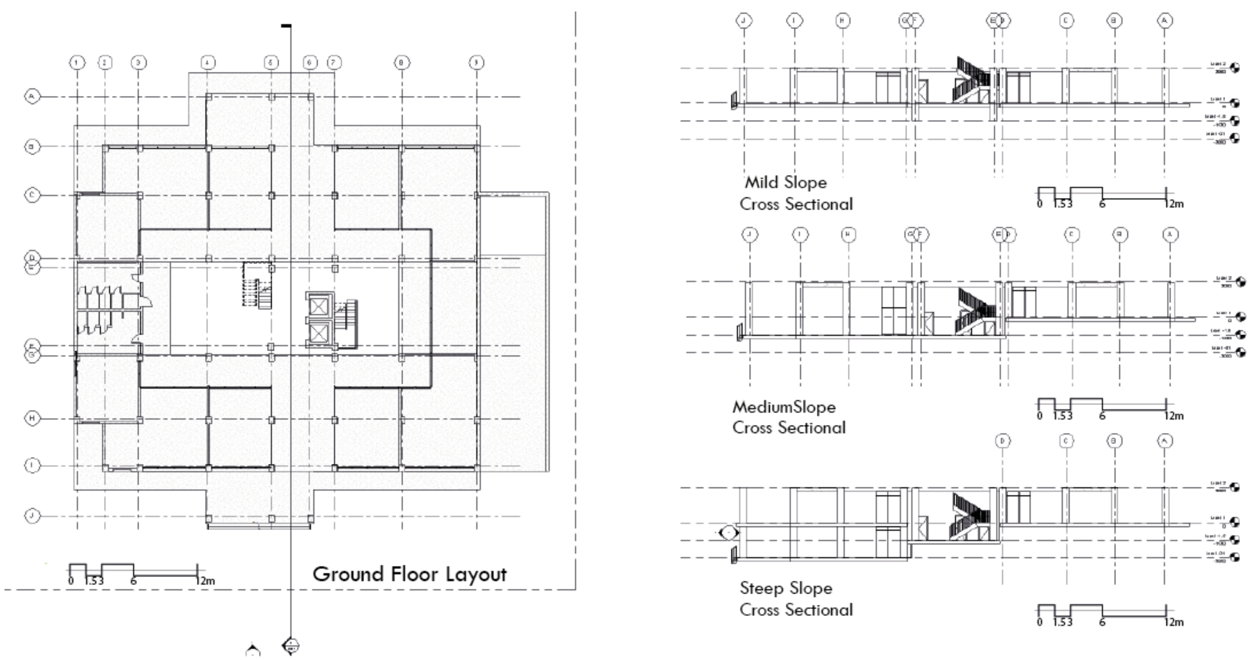


Figure 27: Ground floor design options for varying cross sectional slope conditions (Sections)

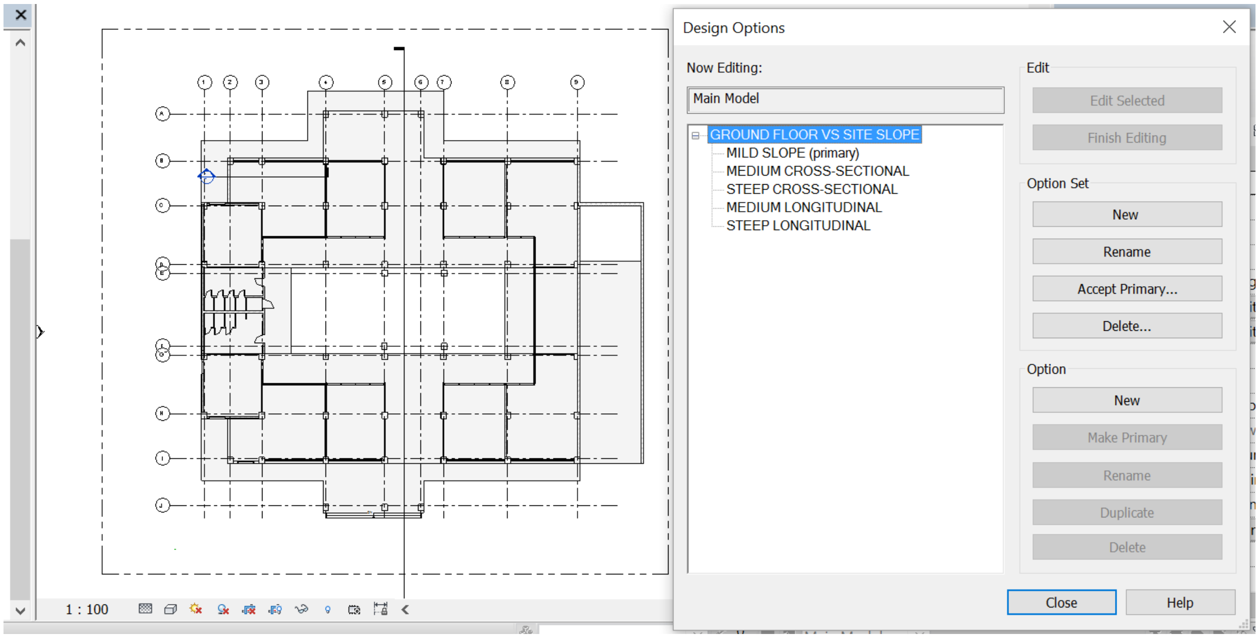


Figure 28: Design options for different ground slope conditions in Revit platform

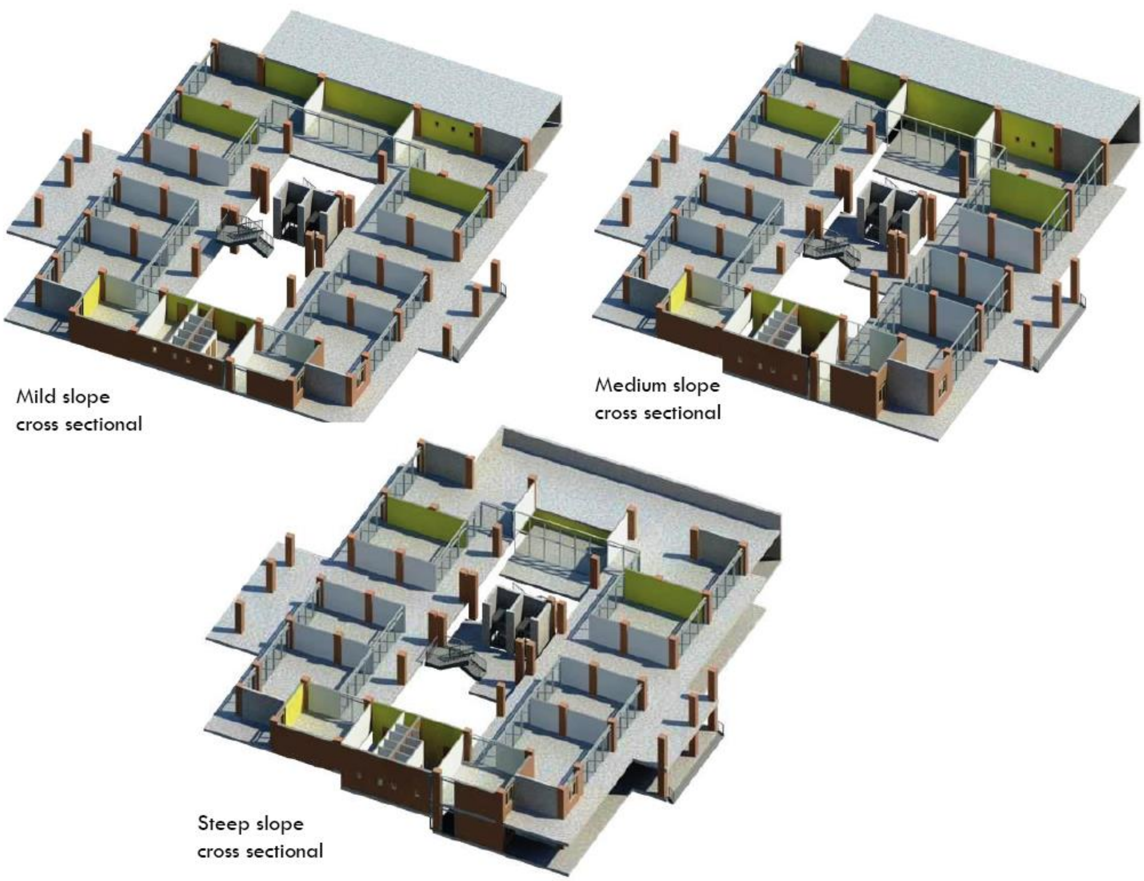


Figure 29: Ground floor design options for varying cross sectional slope conditions (3D)

5.5.2 Function of lower floors

5.5.3 Depending on the level of commercial activity needed three options are proposed for the function of the 1st and 2nd floors. They could be both commercial, both residential and the lower floor commercial and the upper floor residential.

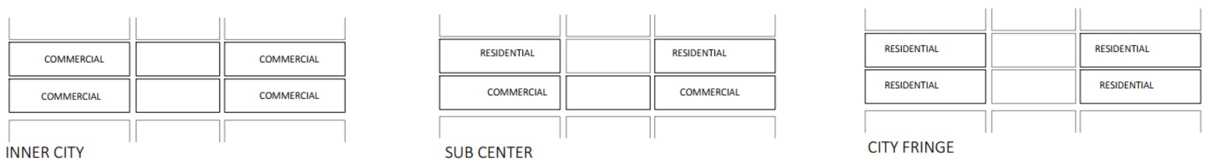


Figure 30: commercial and residential function alternatives in lower floors (1st and 2nd) for different city locations

On the table below it is showed that nine different options are generated from the three ground slope options (Mild, Medium, Steep) and the two functional options (Residential, Commercial). If traditional 2D platform was used all the nine options would be done separately with their bill of quantities and schedules.

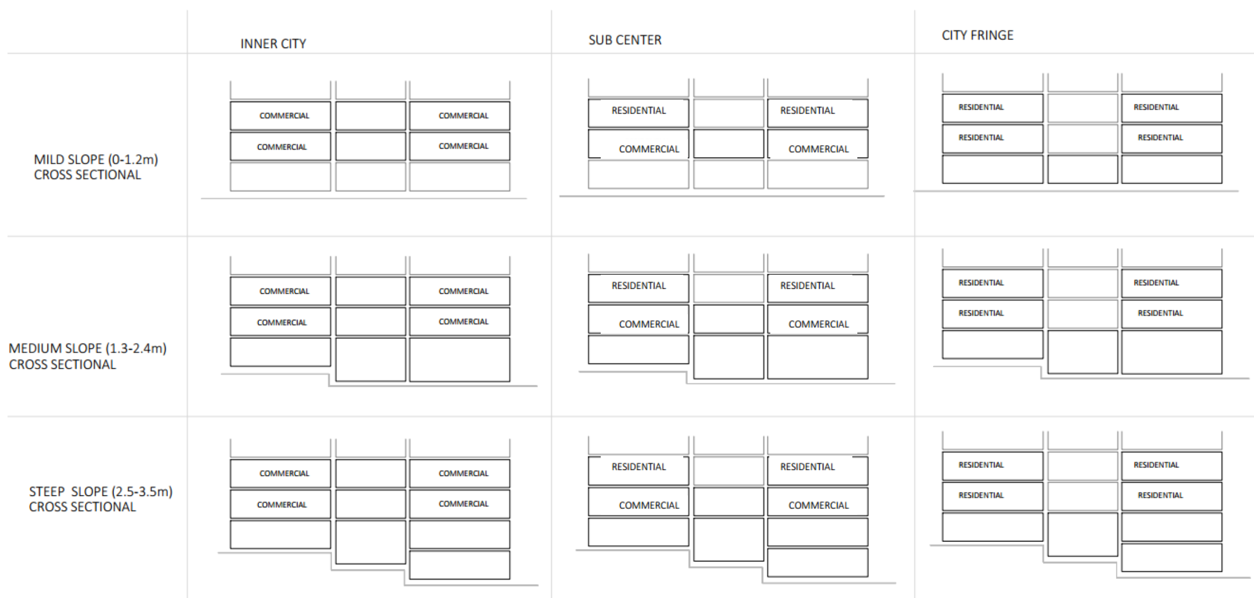
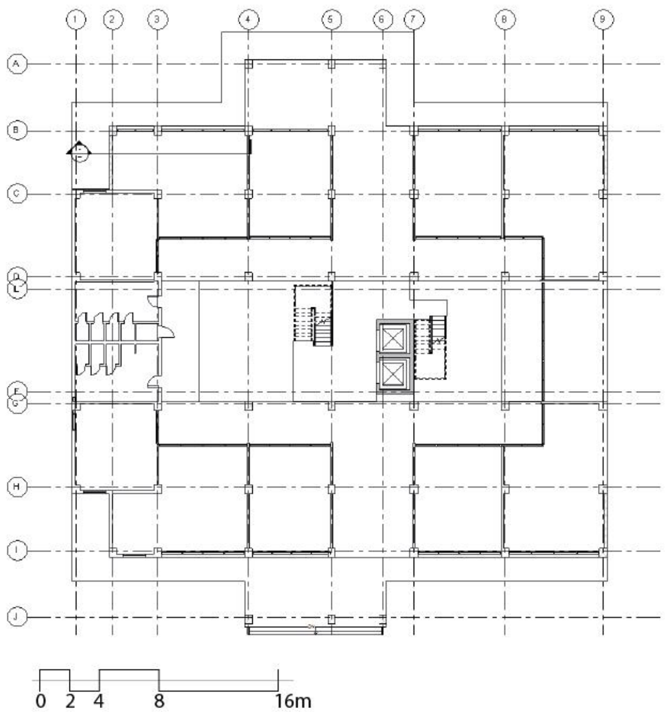
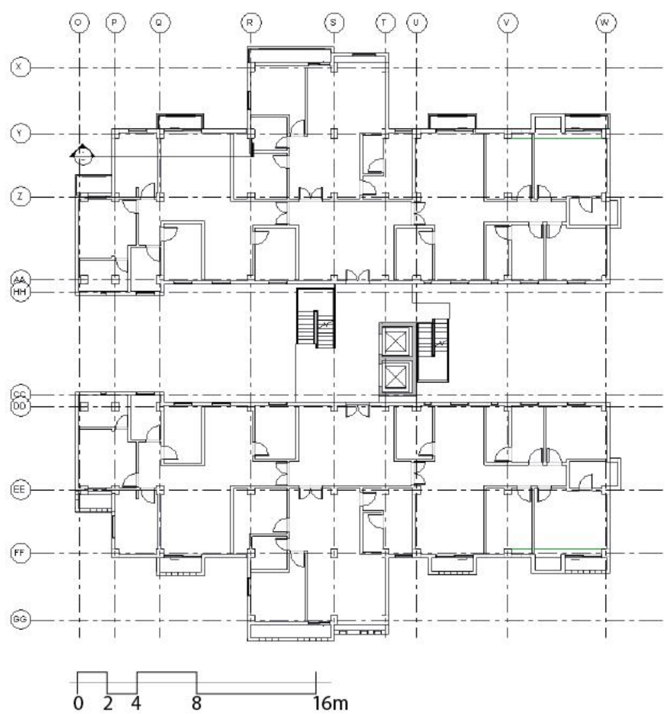


Table 6: matrix of options from the site slope (cross sectional) and functional alternatives in lower floors (ground to 2nd floor)



Commercial option floor layout



Residential option floor layout

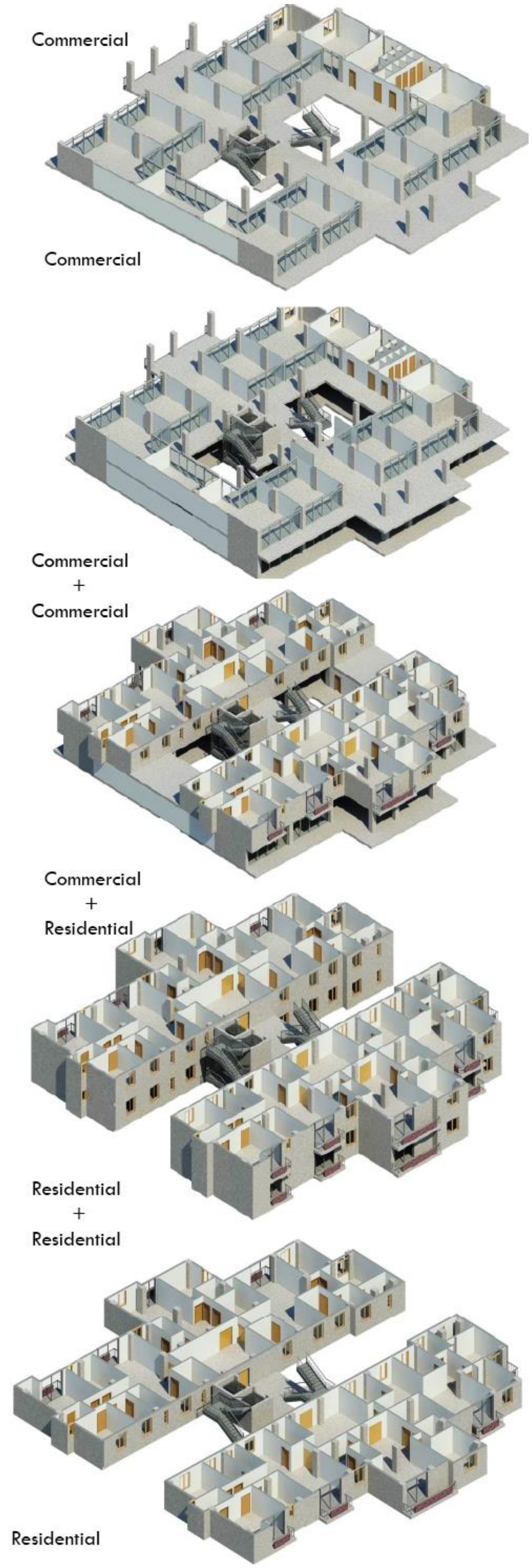


Figure 31: Function of lower floors (1st and 2nd floor functional matrix)

5.5.4 Building orientation (solar) and visual monotony

Below are list of the different conceptual approaches proposed for a typical balcony situation. For more accurate proposals analysis software like Ecotect should be used. The proposals are made as a method to experiment on developing customizable model responding to differing forces.

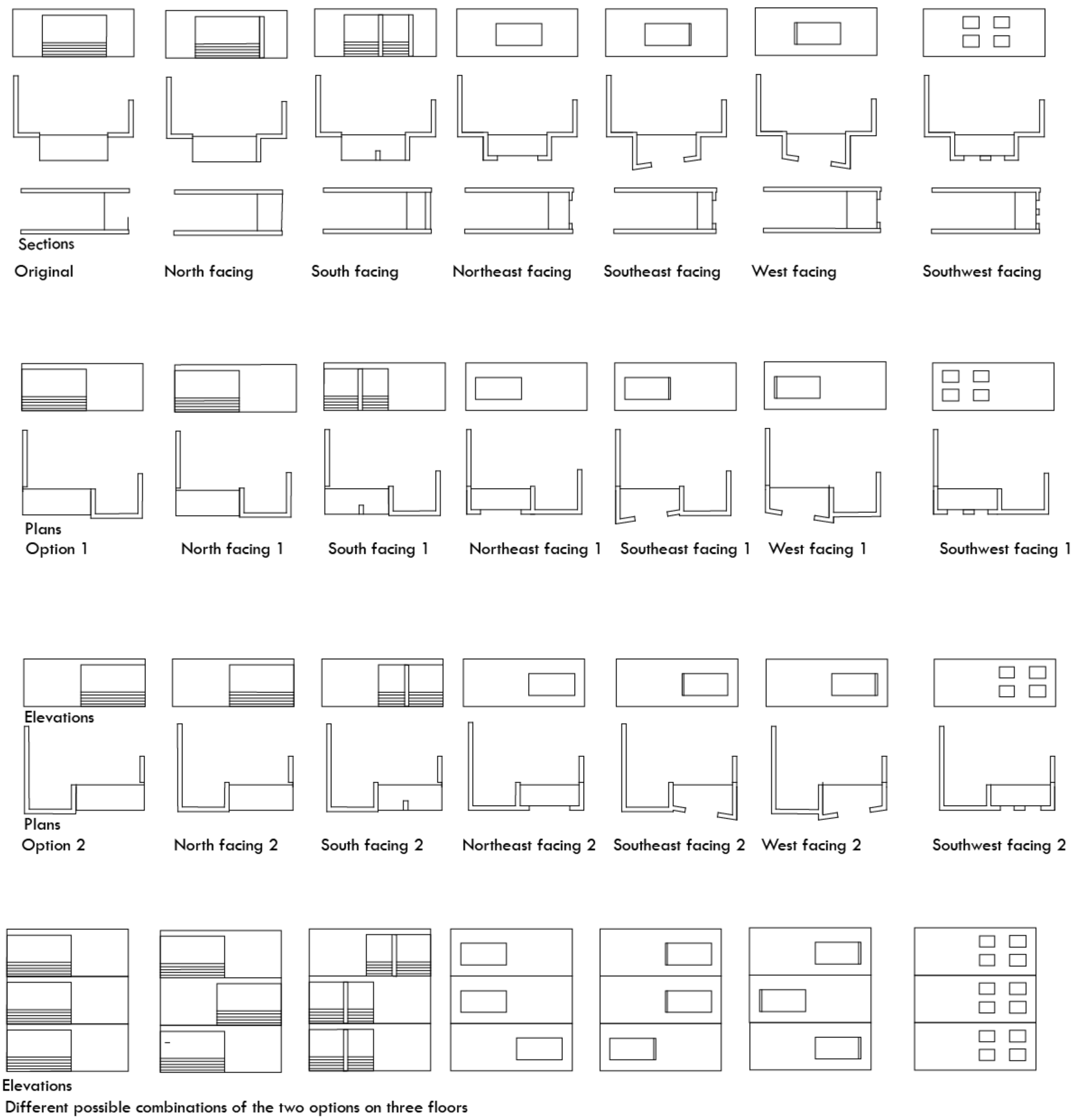


Figure 32: conceptual approaches responding for solar orientation and avoiding visual monotony

5.5.5 Customizable prototype Revit structure

5.5.5.1 Groups, Links and Design Options

The options in the balconies and exterior openings are blocked as groups and could be interchanged within the model option. The totality of the groups, creating the whole façade, is inserted as linked files. The ground slope and lower floor functional options are also inserted as linked files. The primary structure and the linked files are reorganized on the Design Options platform in Revit. This finally formed the customizable prototype.

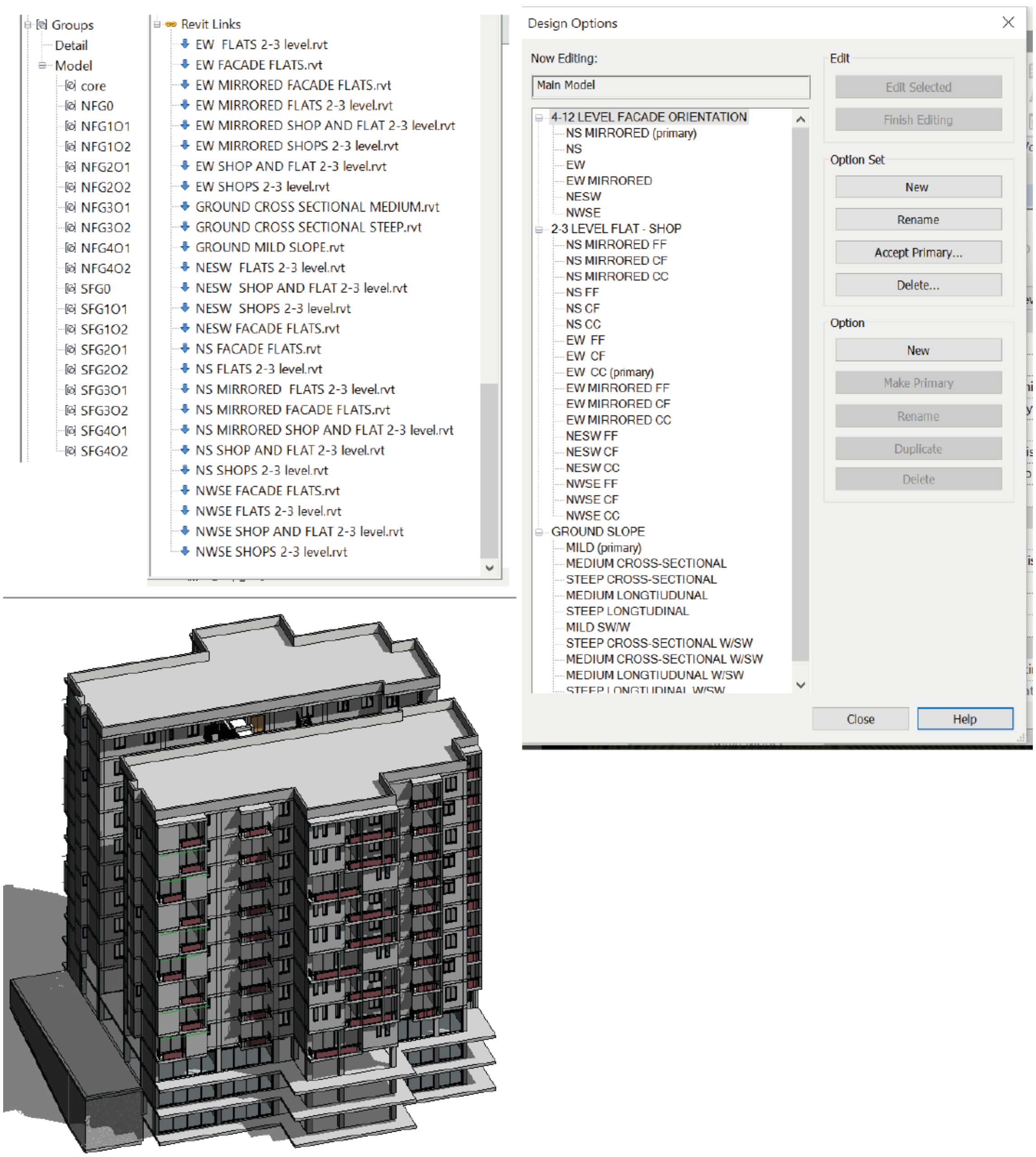


Figure 33: Revit groups, links and options used on the proposal

5.5.5.2 Customizable prototype development structure

in the development of the customizable prototype for the 40/60 housing, the following structure was followed.(see the figure below)

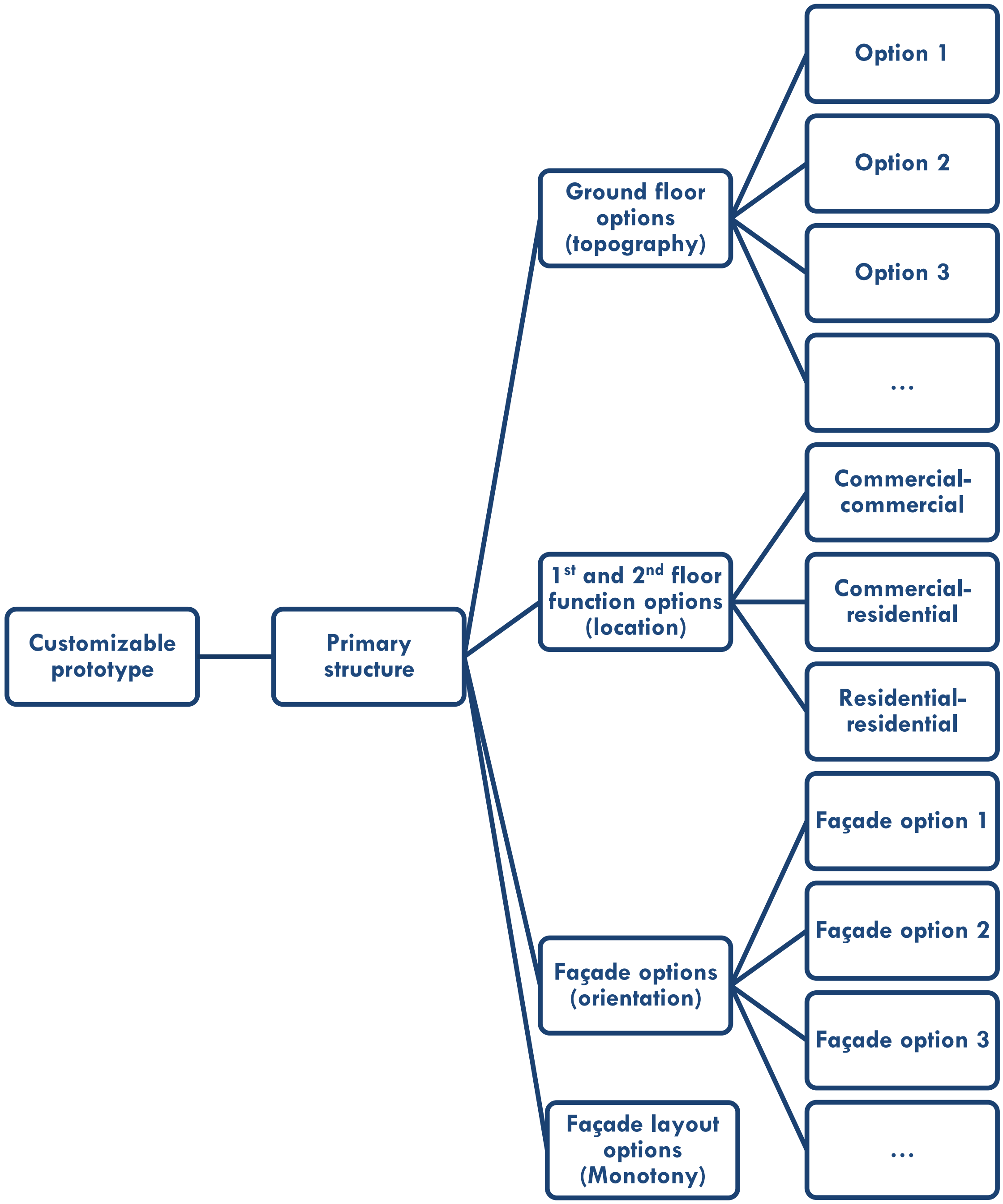


Figure 34: from design options to customizable prototype through BIM

5.5.5.3 Façade layout development structure

With the goal of breaking the visual monotony of the prototype, a façade layout with inbuilt options of variety was developed using the structure below in BIM.

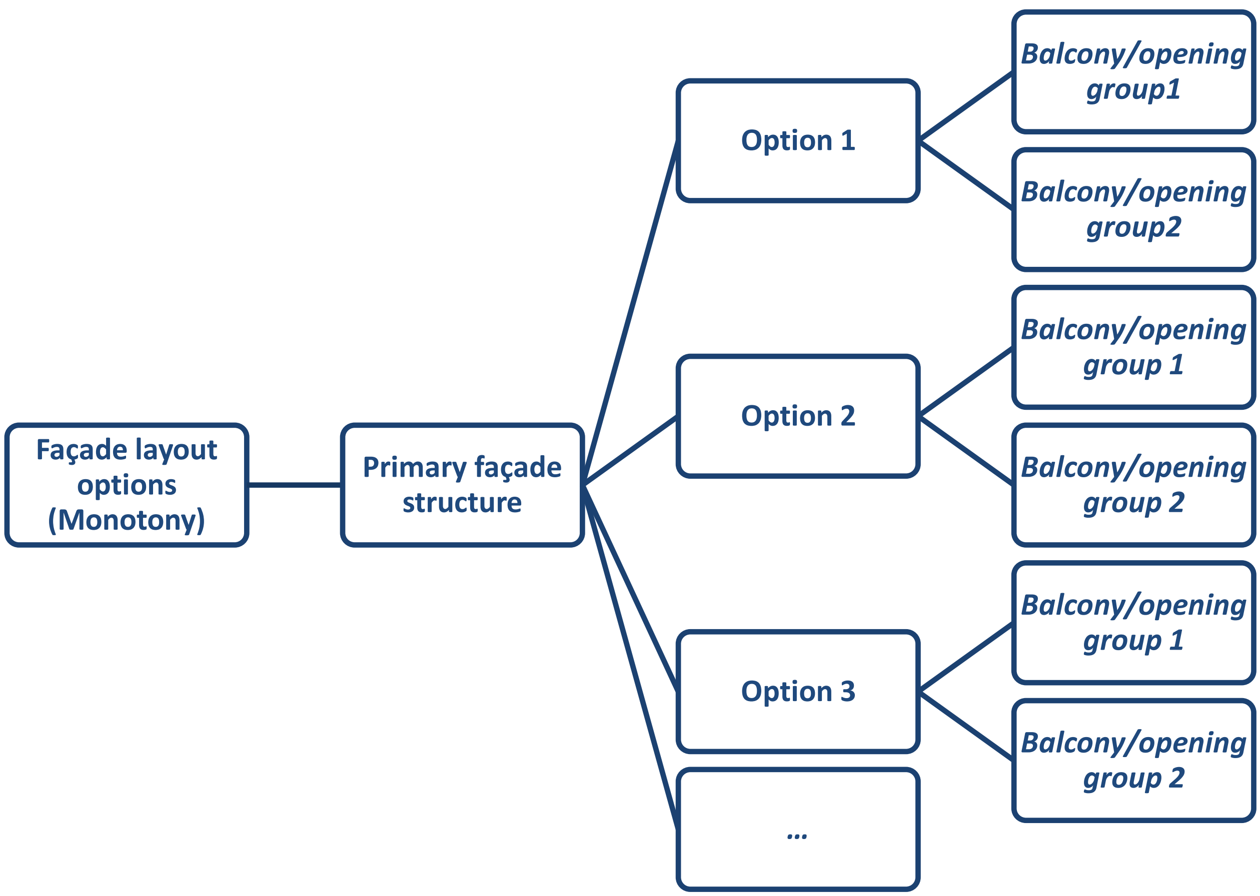


Figure 35: facade layout development with inbuilt options for variety

Figure 36: Facade option for north-south orientation

Figure 37: Facade option for north-south (mirrored) orientation

Figure 38: Facade option for east-west orientation

5.5.5.3.1

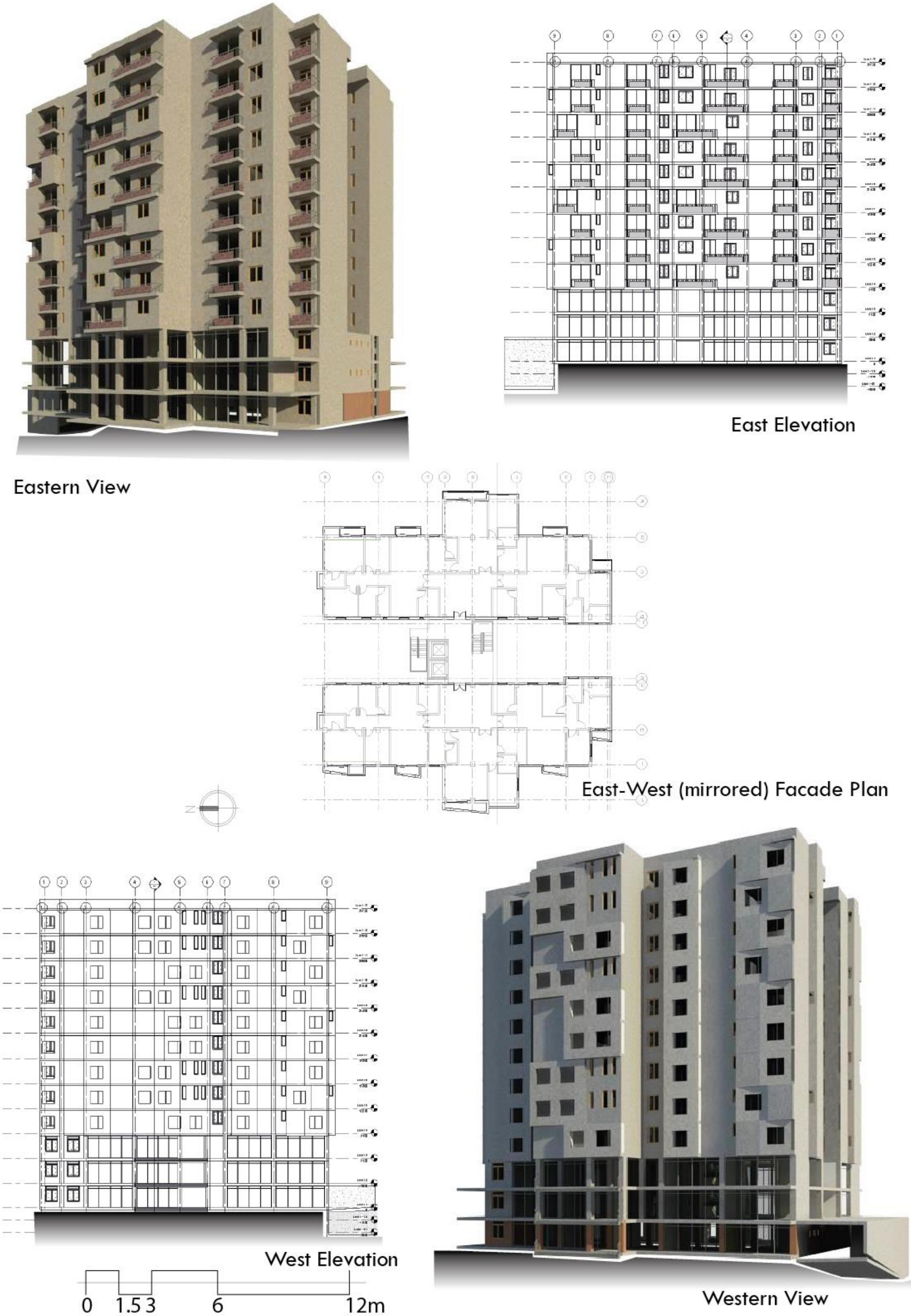


Figure 39: Facade option for east-west (mirrored) orientation

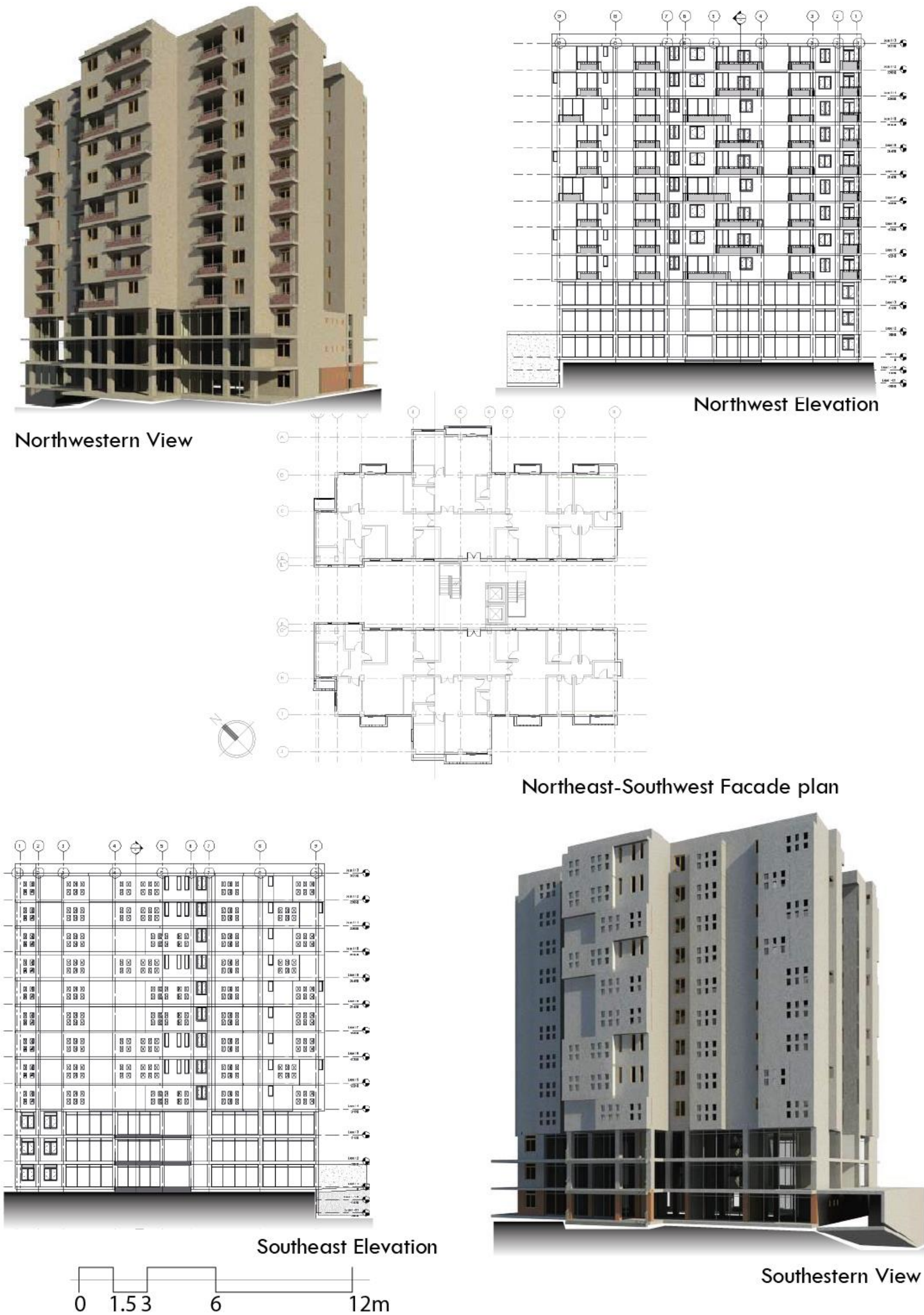


Figure 40: Facade option for northeast-southwest orientation

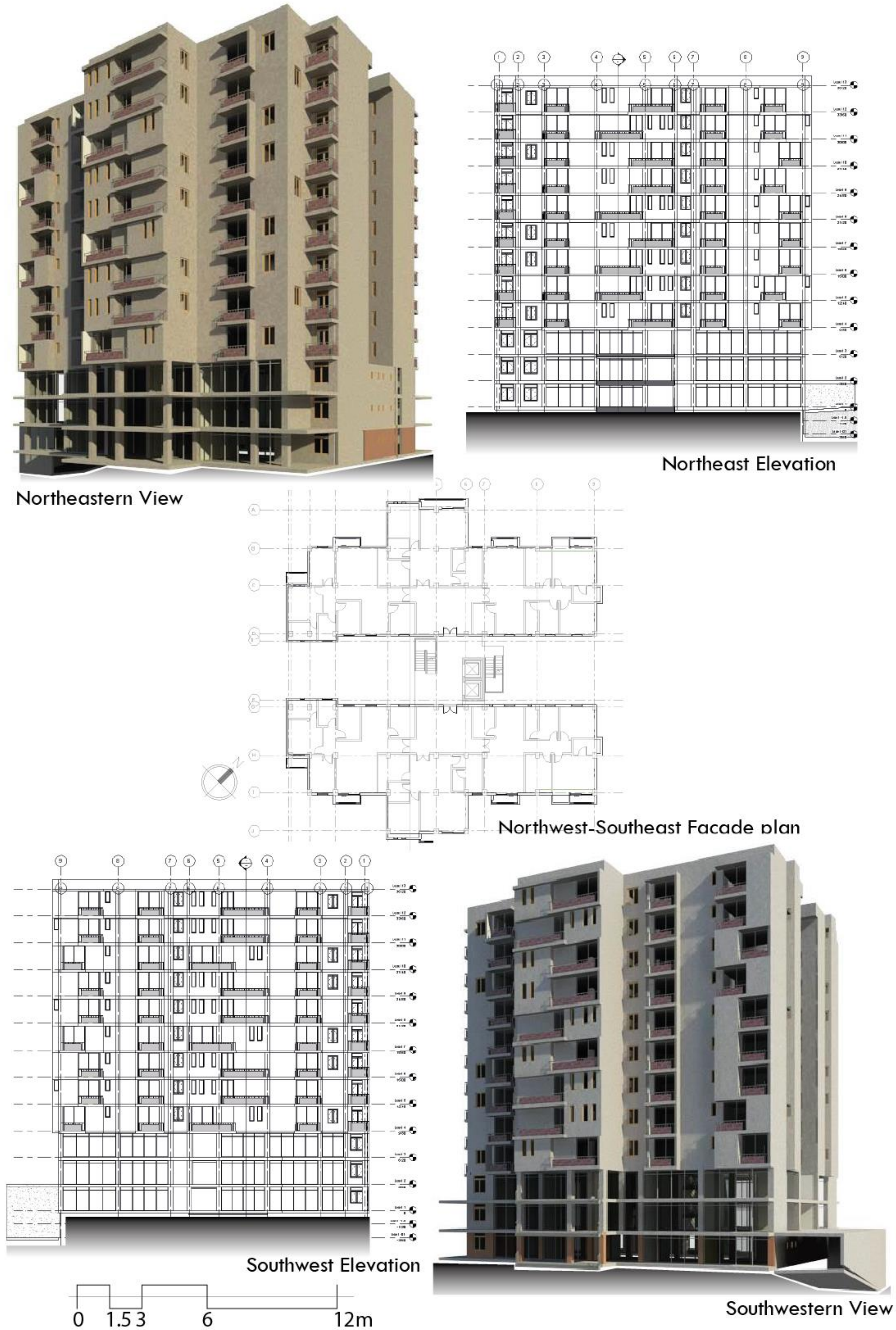


Figure 41: Facade option for northwest-southeast orientation

5.5.6 Step 4: Combining the set of alternatives for a specific situation

One block of the neighborhood design for the 40/60 housing from *Bulbula* site, Addis Ababa was selected to test the developed customizable prototype. The schematic outputs are shown below.

	Block A	**Block B**	**Block C**	**Block D**	**Block E**
Site slope condition	Steep cross sectional (3.5 m)	Medium cross sectional (1.8 m)	Medium cross sectional (1.8 m)	MILD	MILD
1st and 2nd floor function	Commercial-residential (sub street)	Commercial-commercial (main street)	Commercial-commercial (main street)	Commercial-residential (sub street)	Commercial-residential (sub street)
Orientation	Northwest-southeast	North-south mirrored	North-south	East-west	Northeast-southwest
Monotony	Consider vertical (no adjacent similar block)	Consider vertical and horizontal (adjacent similar block c)	Consider vertical and horizontal (adjacent similar block b)	Consider vertical (no adjacent similar block)	Consider vertical (no adjacent similar block)

Table 7: checking the parameters for customizing the prototype

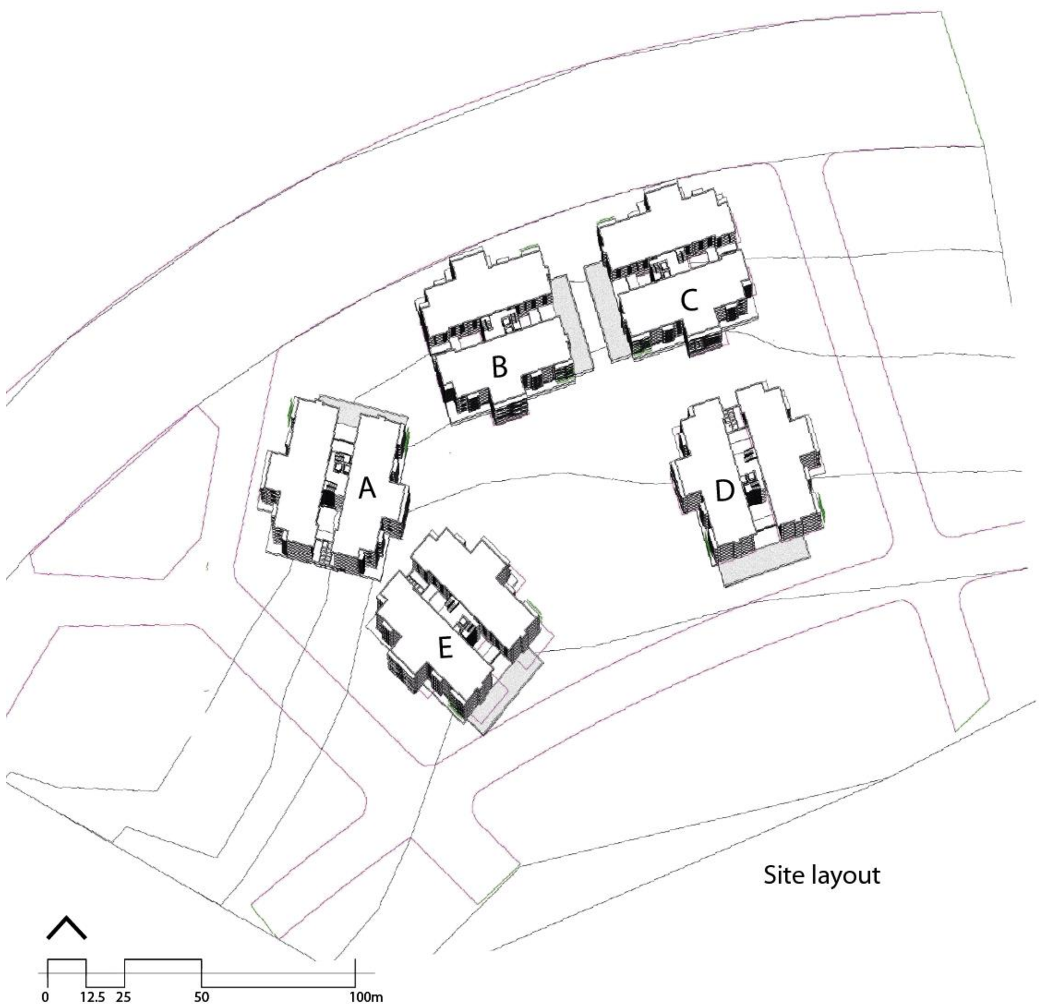


Figure 42: site layout in a test neighborhood

Figure 43: customized blocks illustration

Once the customization process is done for the individual blocks, all construction documents (drawings, quantities, schedules) could be generated automatically from the BIM platform (in this case Revit Architecture) for commencing construction or bidding. The modification shall include structural and MEP alternatives corresponding to the architectural design options as the floor loading and layout changes for each architectural design option.

6 Conclusion and Recommendation

This paper has successfully introduced a method of designing building prototypes with inbuilt customizable parts by using Building Information Modeling platform (specifically Revit Architecture application) for contexts of rapid and labor intensive construction systems like the case of IHDP in Addis Ababa (specifically 40/60).

The findings could be used as a spring board to push the AEC industry of Ethiopia in general and IHDP in particular to state-of-the-art technological advancements in two dimensions. Firstly, a step by step introduction of BIM technology to the local AEC industry that would help the industry in detaching it from the inefficiencies of the traditional 2D based system. Secondly, the introduction of mass customization to the IHDP would lead to efficiency, end user satisfaction and better city image.

Further study is required to precisely analyze and document the customization needs as well as to come up with better alternative designs adapting to the customization needs. Customization needs from end users, adaptation requirements due to user changes and cultural differences, building material customization, neighborhood design level customization, are some of the areas that need further research. Different scientific approaches of designing more responsive alternatives for different scenarios need to be explored. Scientific methods of approaching the design beyond the technical aspects like the integration of *GIS* data within the BIM platform for topographic response and the use of environmental analysis tools like *Ecotect* for analyzing and assessing environmental forces is highly recommended for further investigation.

Even with the four site forces selected for customizing the 40/60 prototype, managing the design options manually was rather difficult. The number and variety of design options when dealing with more customization forces would obviously make the change management extremely difficult; if not impossible. Therefore, visual programming tools formulated for such BIM platforms like *Dynamo* are recommended to systematically handle such huge number of variations. Algorithmic design methods may also be employed for special programming needs.

For a successful and sustained implementation of BIM in the AEC industry of Ethiopia, the way building professionals are educated needs to supplement such technology. More BIM tools, practical experience, international exposure and special focus teamwork are some of the recommended focus areas for training building professionals so as to exploit BIM in a sustained and comprehensive way.

After analyzing the challenges of implementing BIM, it is recommended to start with public projects as a show case where the common challenges faced like getting building permit are minimal. For example, the IHDP could adapt BIM from conceptualization through design and construction; transferring and precise registration of users and units, to maintenance and facility management.

For encouraging privately funded building projects to exploit BIM, it is recommended to establish separate building permit office for BIM applying projects. Floating design competitions and construction bids with strict BIM usage requirements could also be used as encouraging factors.

The local consulting firms, building contractors and micro and small enterprises should be trained to aim in the direction of BIM. It is recommended for the micro and small enterprises to develop and capacitate in computer controlled production and manufacturing of building parts so as to stay within the system even with the advancement of the construction technology.

My final recommendation goes to the BIM application used in this thesis, Revit architecture. I recommend introducing sub-options in the design options tool. This would facilitate in structuring the alternative designs in hierarchical manner.

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Appendix I: Original architectural design documents of one of the 40/60 housing prototypes

(Source: ADDIS ABABA SAVING HOUSES DEVELOPMENT ENTERPRISE)

Appendix II: 40/60 neighborhood design layouts

(Source: ADDIS ABABA SAVING HOUSES DEVELOPMENT ENTERPRISE)