İSTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

3D-GIS BASED PROCEDURAL MODELING IN CONTEMPORARY URBAN PLANNING AND DESIGN PRACTICE

M.Sc. THESIS

Cem DEMİR

Department of Urban Design

Urban Design Programme

DECEMBER 2016

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GÜNCEL KENTSEL PLANLAMA VE TASARIM UYGULAMALARINDA 3B-CBS TABANLI YORDAMSAL MODELLEME

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FOREWORD

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City and Regional Planner

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ABBREVIATIONS

GIS	**:** Geographic Information Systems
CE	**:** CityEngine
PM	**:** Procedural Modelling
CGA	**:** Computer Generated Architecture
IMM	**:** Istanbul Metropolitan Municipality
BM	**:** Beylikduzu Municipality
BDPA	**:** Bylaws on Planned Areas
BIPN	**:** Beylikduzu Implementation Plan Notes
BC	**:** Building Coverage
FAR	**:** Floor Area Ratio
GCA	**:** Gross Construction Area

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3D-GIS BASED PROCEDURAL MODELING IN CONTEMPORARY URBAN PLANNING AND DESIGN PRACTICES

SUMMARY

The cities keep developing rapidly all over the world. Urban planning and urban design disciplines are striving to enhance new theoretical concepts in order to keep up with these changes. Various researches commonly claim that the outcomes that are generated with the traditional planning techniques in the world and Turkey fall short in providing the livability of urban space and the design quality.

The dynamical structure of the planning regulations in Turkey causes frequent changes in the tools and rules applied in spatial planning. The changes in the regulatory tools caused by the law, regulations and plan notes make it harder to investigate them in the spatial changes that will take place in the cities.

On the other hand, the new information-based techniques are increasingly used as a result of the developments in technology create remarkable tools for spatial planning practices. Especially three dimensional visualization tools are used in order to produce high-class designs in spatial planning all over the world. Mostly, the three dimensional urban models are produced by transferring two dimensional drawings into particular software for some reason and they are generally produced to describe the current situation. However, novel techniques in 3D modeling field are offering workflows for aiding the design phase. By using such tools, valuable contributions can be achieved in design aspect of planning processes.

Procedural modeling steps forward among these tools. With procedural modeling tools, quite remarkable outcome can be produced by means of the operations that identify the small data entries with procedural codes. In this modeling methodology, it is possible to dynamically visualize three dimensional representations of design decisions by defining regulative codes into procedural codes.

In this thesis, the codes and tools identified in the current urban planning and designing practices in Turkey are converted into procedural modelling parameters and thus the operation rules that will form the three dimensional models have been set. Then, the current implementation plan of the selected field is transformed into a three dimensional interactive model. The city blocks, functions, land use decisions and housing rights, which are described in the plan, are interpreted with different designing alternatives within this parametrical system. After these alternative designs are modeled in compliance with the criteria specified in the plan and regulations, the quantitative evaluation of these models are conducted. This evaluation includes reports of estimations such as demographic data, calculations of areas, costs and value calculations and consumption demands.

As a consequence, the response capacity of produced three-dimensional GIS based procedural modeling system on urbanization and planning policies is investigated. Additionally, opinions on the utilization of this system within the framework of sustainable planning practices are expressed. Meanwhile, by criticizing the arguement that legal codes exceedingly restrict the design process, it is showed that various design alternatives can be created within this interface by utilizing procedural modeling.

GÜNCEL KENTSEL PLANLAMA VE TASARIM UYGULAMALARINDA 3B-CBS TABANLI YORDAMSAL MODELLEME

ÖZET

Tüm dünyada şehirler çok hızlı bir şekilde büyümeye devam ediyor. Kent planlama ve kentsel tasarım disiplinleri de bu değişime ayak uydurabilmek amacıyla yeni kuramlar ve yaklaşımlar geliştirmekte ve bu değişime uyum sağlama gayreti göstermektedir. Kentlerin durdurulamayan nüfus artışı beraberinde ciddi çevresel, sosyal, ekonomik ve mekansal sorunlar ortaya çıkarmaktadır. Bu sorunların çözümü için gerekli tespit, analiz ve değerlendirme süreçleri büyük miktarlarda veri gerektirmektedir. Bu büyük verinin ve bu sorunların yönetiminde alışılmış bakış açıları yetersiz kalabilmektedir. Dünyada ve Türkiye'de yaygın planlama pratikleriyle üretilen plan çizimleri ve raporlarının kentsel tasarıma konu olan mekanın yaşanabilirliğinin ve mekansal kalitesinin sağlanmasında yetersiz kalabildiği iddiası bir çok araştırmada paylaşılmaktadır. Böylece, kentsel alanın yönetim ve planlamasında alışılmış olanların dışında, yeni parametreler eklenmektedir.

Türkiye'deki planlama mevzuatının çokça değişen ve istikrarsız yapısı, mekansal planlamada kullanılan araç ve kuralların sıklıkla değişime uğramasına neden olmaktadır. Yasa, yönetmelik ve plan notlarının getirmiş olduğu düzenleyici araçlardaki değişimlerin, kentlerde yaratacakları mekansal sonuçları incelemek gün geçtikçe daha çok zorlaşmaktadır. Söz konusu araçların değişimiyle planlamanın kentsel çevreyi düzenleme biçimi de değişmektedir. Bunun yanında, genel anlamda Türkiye'de sonuç ürün olarak üretilen planların, detaylı sosyo-ekonomik ve çevresel analizlere dayalı, mekansal vizyon ve tasarım stratejilerini temel alan bir yapıda olup olmadıkları tartışmaya açıktır. Bu günün pratiklerinde, plancıların ve kentsel tasarımcıların, kente dair mekansal kararlarında tasarım becerisi ve kalitesinden daha çok mekanik inşaat alanı hesaplarına önem verdiği söylenebilir. Teknik olarak, alışılmış plan üretim araçlarının kent plancısını yaratıcı düşünce üretimi noktasında engelledikleri ve bu araçların, bilgi, iletişim ve temsiliyetle ilgili sorunlara sebep oldukları araştırmalarla ortaya konmuştur.

Diğer yandan, teknolojinin gelişmesiyle kullanımı artan bilgi sistemlerine dayalı yeni teknikler, mekansal planlama pratikleri için dikkate değer araçlar yaratmaktadır. Planlama ve kentsel tasarım pratiklerinde, müdahale edilmekte olan kentsel çevreyi görselleştirmek, tasarımla ilgili fikir alışverişi yapmak ve farklı tasarım senaryolarını deneylemek amacıyla yeni tasarım yöntemlerinin araştırılması bir zorunluk haline gelmektedir. Bu yöntemler genellikle kentsel çevreyi tüm boyutlarıyla ele almayı ve her tür bilgiyi yöneterek sentezlemeyi sağlayan kapsamlı araçları içermektedir. Bu çalışmanın merkezinde, kentsel planlama süreçlerinin üç boyutlu modelleri içermesi gerektiği hipotezi bulunmaktadır. Dünyada özellikle üç boyutlu görselleştirme araçları, mekansal planlamada kaliteli tasarımlar üretebilmek amacıyla kullanılmaktadır. Yaygın uygulamalarda üç boyutlu kent modelleri, iki boyutlu

çizimlerin genellikle görselleştirme amacıyla belli programlara aktarılmak suretiyle oluşturulmakta ve kent modelleri genellikle halihazır durumu betimlemek amacıyla üretilmektedir. Bunun yanında belirli bir alandaki, tasarımı bitirilmiş bir projenin tanıtımı gibi amaçlarla görselleştirilmesi de yaygın kullanımlardan biridir. Fakat üç boyutlu modelleme alanındaki yeni teknikler tasarım aşamasını da destekleyecek çalışma yöntemleri sunmaktadır.

Bu araçlar içinden yordamsal modelleme olarak Türkçe'ye çevrilebilecek olan "procedural modeling", bahsedilen araçlardan biri olarak öne çıkmaktadır. Yordamsal modelleme araçları vasıtasıyla, küçük veri girdilerini yordamsal kodlar ile tanımlanan işlemler yardımıyla oldukça büyük sonuç ürünlerine dönüştürebilmek mümkündür. Bu modelleme yönteminde, ilk adımda modelleme programının dijital girdileri hangi şartlarla, hangi sıra ve ne şekilde işleyeceğinin tariflendiği "kural kodları" üretilerek, bir parselden anlamlı bir yapılaşma modeli oluşturacak temel komut zinciri tanımlanmaktadır. Bu kodlar, modelleme yapılırken değiştirilebilecek olan parametreleri içermektedir. Söz edilen parametreler parsel bazında CBS tabanlı bilgilere bağlı olarak veya kullanıcı tarafından değiştirilerek, arzu edilen model oluşturulabilmektedir. Bu çalışma özelinde örnek vermek gerekirse, planlama mevzuatında tanımlanan yazılı yapılaşma koşullarının yordamsal parametreler olarak tanımlanması amacıyla yazılacak bir kodun, kentsel tasarım kararları olarak üçüncü boyutta karşılığını hızlı ve dinamik bir arayüzde görselleştirebilmenin mümkün olacağı savıyla yola çıkılmıştır.

Tezde, öncelikle 3 boyutlu kent modellerinin, yürürlükteki bir planın tanımladığı kentsel çevreyi tasavvur edip edemeyeceği sorgulanarak, bir örnek alan çalışması yapılmıştır. Bir diğer önemli soru da Türkiye'de hızla değişen planlama mevzuatının, yeni teknolojilerden biri olan 3 boyutlu CBS tabanlı yordamsal modelleme teknikleriyle entegre olup olamayacağıdır. Bu sorular ışığında, Türkiye'de mevcut kentsel planlama ve tasarım pratiğinde tanımlanmış olan kodlar ve araçlar, yordamsal modelleme parametrelerine dönüştürülerek üç boyutlu modelleri oluşturacak işlem adımları ve kuralları oluşturulmuştur.

Bu işlemlerde çekme mesafeleri, taban alanı, kat sayısı, yapı yüksekliği, yapı yaklaşma mesafeleri ve emsal gibi bir çok parametreyi içermektedir. Planlama sisteminde tanımlı kodların yapılaşmayı tam anlamıyla tanımlayamadığı düşünülen noktalarda yeni parametreler eklenerek, yapılaşma kodları oluşturulmuştur. Her yapı parseli özelinde, bu parametrelerdeki her değişim, program tarafından sonuç üründe güncellenerek, kullanıcıya bu değişimin görsel sonucunu gözlemleme imkanı verebilmektedir. Koda göre; parsel içinde, yapı oturum alanı dışındaki alanlar, seçime göre yeşil alan, sert zemin veya otopark alanı gibi düzenlenebilirken, bir parselde bir veya birden fazla yapı yapılabilmektedir. Yapıların oturum düzeni, modelleme esnasında önceden tanımlanmış oturum tipolojileri seçilerek değiştirilebilmektedir. Cephe ve çatı detayları, pencere ve duvar genişlikleri gibi temel özellikler başta olmak üzere, bir çok parametreyle düzenlenebilmektedir. Yapı parselleri dışında bu sisteme yol orta çizgileri ve topoğrafya verisi eklenmiştir. Yol ve parseller, topoğrafya üzerine oturtularak alanın gerçek dokusu görselleştirilmiştir. Yollar; yol genişliği, şerit sayısı, yaya ve bisiklet yolları, kent mobilyaları gibi bir çok parametrelerle kontrol edilebilmektedir.

Oluşturulan bu kodlar, genel planlama araçlarını içerdiğinden, bir alana veya bir tasarım tarzına özgü değil, her alanda kullanılabilecek ve farklı tasarımlara izin verebilecek bir sistem sunmaktadır. Bu ön çalışmanın ardından oluşturulan kodlar, İstanbul'un Beylikdüzü ilçesinde seçilen bir çalışma alanında, yürürlükteki uygulama planına tanımlanmıştır. Planda tariflenmiş olan yapı adaları, fonksiyonlar, arazi kullanımı ve yapılaşma kararları, bu dinamik modelleme sisteminde, alanın tamamı için tanımlanan farklı tasarım kriterleriyle yorumlanarak, iki farklı kent modeli oluşturmak amacıyla kullanılmıştır. Bu alternatif tasarımlarda, yürürlükteki plana ve yönetmelikte belirlenmiş olan yapılaşma kararlarına uygun ve uyumlu bir tasarım içeriğine sahip; monoton bir model yerine gerçekçi bir kent modeli oluşturabilmek amaçlanmaktadır.

Aynı çalışma alanında, aynı plan kararları kullanılarak üretilen iki alternatif tasarım uygulandıktan sonra, modellerin sayısal değerlendirmesi yapılmıştır. İki tasarımda da kullanılan mevcut parsel dokusu ve plan durumları, coğrafi bilgi sistemi kaynaklı olduğundan dolayı, içinde birtakım analitik bilgiler içermektedir. Bununla birlikte, modelleme esnasında yapılan tüm işlemler sonucunda her bir parselin içerdiği yapılaşmaya ait nicel veriler gözlenebilmektedir. Bu değerlendirme; nüfus, yoğunluk, bağımsız birim sayıları gibi demografik verileri; farklı arazi kullanımlarının toplam inşaat alanları, tahmini enerji tüketimleri ile maliyet ve değer hesaplamalarını içermektedir. Bu sonuç raporlamaları verilen her yapılaşma kararının ne gibi sonuçlar oluşturacağı gözlemlenebilmektedir.

Sonuç olarak, oluşturulan üç boyutlu coğrafi bilgi sistemleri tabanlı yordamsal modelleme sisteminin, kentleşme ve planlama politikalarında hızlı çözüm üreten bir yapı ihtiyacına ne denli yanıt verebildiği ortaya konmaktadır. Bu çalışmada üretilen modelleme sistemiyle bir plan, plan notları, yasa ve yönetmelikler temel alınarak oluşturulan kentsel tasarım alternatifleri göstermektedir ki; mevzuatın içerdiği yazılı ifadeler yapılaşma şartlarında esneklik sağlamak yerine belirsizlik yaratmaktadır. Bu durumu oluşturan koşulların tanımlanması ve daha analitik koşullara bağlı bir yapıya kavuşmasında bu çalışmaya benzer yordamsal modelleme uygulamalarının yardımcı olacağı düşünülmektedir. Diğer yandan, imar planlarının ve planlama mevzuatında yer alan yasal tanımlamaların tasarım üzerinde fazlasıyla kısıtlayıcı bir rolü olduğu savı da eleştirilerek, yordamsal modellemenin bu arayüzde oynayabileceği roller araştırılmıştır. Aynı plan kurallarına dayanılarak parsel bazında birbirinden çok farklı yerleşim ve biçim alternatiflerinin üretilebilecek olduğu, çalışmada deneyimlenmiştir. İmar planı kararları ve yapılaşma koşulları genel anlamıyla çok fazla parametre ve kriter içeriyor gibi gözükse de, aslında bu sınırlar içerisinde, tasarımcıya geniş bir alan bırakmaktadır.

Bunun yanında, bu sistemin sürdürülebilir planlama pratikleri çerçevesinde nasıl kullanılabileceğine dair görüş ve öneriler aktarılmaktadır. Kentlerin hızla geliştiği günümüzde, kente dair kararların gelecekteki etkilerini görmek ve daha duyarlı imar kararları üretmek kritik öneme sahiptir. Yordamsal modellemenin raporlama özelliği sayesinde mekansal senaryoların çevresel, ekonomik ve sosyal etkileri daha etkin bir şekilde analiz edilerek duyarlı bir planlama pratiği tanımlanabilir.

Şehir plancıları çizdikleri planın tüm boyutlarıyla nasıl bir kentsel çevre yaratacağını zihinlerinde canlandırabildikleri varsayımıyla hareket etmektedir. Bu varsayımın bir yanılgı olduğu, kentlerimiz için yapılan planlardan birkaçı incelendiğinde bile kendini göstermektedir. Plancı ve tasarımcılar mekansal kararlarının yaratacağı çevreyi zihinlerinde canlandırmaya çalışmak yerine, yeni teknoloji ve yöntemler kullanmalıdırlar.

1. INTRODUCTION

As a broadly accepted fact, purpose of urban planning is to create livable cities. Thus, urban planning and urban design processes must have a comprehensive design content that is accomplished by not only geometric consistency but also quantitative stability. New concepts were emerged in these fields within the last decades such as sustainability and smart cities. Means of these concepts are widely researched and are being increasingly adopted by many cities. Meanwhile, technology is advancing at a full speed. Computer technologies offer great tools for planners. By considering all of these facts, it is obvious that future of spatial urban planning will be shifted into a more comprehensive and interactive state.

As a high-profile concept, sustainability is a critical matter in contemporary urban planning. As rapid urban developments have been occurring in every part of the world, phenomenon of sustainability is becoming a key issue. As the global population continue to swarm into urban areas, sustainable development challenges in cities will surely increase (United Nations, 2014). High levels of urbanization give rise to numerous social and environmental problems. Thus the agenda of urban planning and design is shifted to find a way out the contagious effects of incautious urban developments. Variety of tools have been developed for urban decision-makers to aid the process of strategic decisions. Taking advantages of technological improvements, tools such as GIS are seen as a helper to problems decision-makers face in mitigating the problems of unplanned urban developments (UN-HABITAT, 2016).

On the other hand, circumstances of today's global world, encourage the cities to compete and to become more resilient, smart and adaptive. Today, the world is increasingly global and interconnected more than ever (United Nations, 2015). Dynamically changing economic and social relationships force decision makers to put away comfortable preconceptions of rapid development and complete city. It is started to be understood that the cities should be capable of adapting to population shifts, wealth and climate changes (Fallis, 2013).

The competition of smart and adaptive cities, transforming the definition of "smart" although it is a new adaption into urban planning approaches. The concept of smart cities is relatively new since it takes a departure from information technologies and novel means of communication. Deliberations about the way these technologies would contribute to the functions of the cities, capacity to compete and productivity are on the origin of smart city concept. Moreover, the matters about finding solutions to the problems such as poverty, social discrimination and inadequate urban environments compose critical input in creating the smart city concept. Washburn et al. (2010) define the smart city by its strong relationship with computing technologies. Smart cities' services ought to be more intelligent, interconnected and efficient by using new technological developments. Today cities are becoming smarter by the automation of services, people, buildings, traffic etc.

Coming from the emergence of the concept, the smart city addresses improvement on the functioning and efficiency of the city services, innovative solutions for the detrimental effects of fast urban development such as social segregation, poverty and unsustainable environments. Towards that aim, cities are under pressure of adopting smarter methods for acquisition of new types of urban data, management of urban plans and policies and intercommunication with both its residents and their global opponents. The management and planning systems of the cities are also becoming more intelligent (Batty et al., 2012). The smart city concept does not only include the automatization of the city's routine functions but also the paradigms that will improve the productivity in monitoring, analyzing and planning processes of the decision-makers and that will provide new solutions to the improvement of living standards. Besides, these paradigms change the way of handling the cities by evaluating the actualization and implementation processes of the plans in the long run. In addition, the ongoing increases in the new urban information types and the issues such as planning and policy making, which require an interaction with the public, lead to developments in public participation (Batty et al., 2012). This situation conduces toward a shift in the context that urban planning deals with.

The interest on concepts such as sustainability or smart cities are already key concerns for planning. Thus, increasing demand for more comprehensive approaches lead cities to abandon conventional methods in order to achieve sustainable planning systems. Therefore, responsible development plans in which principles of suitability are taken into consideration, have crucial role in sustainable urban developments. These plans require novel means of analysis, preparation and communication.

The city is not a static entity, it is complex and dynamic. So designers who are responsible for creating spatial visions for the city should not create final products, but rather should define a framework that may evolve and adapt future changes. Even the spatial plans should not be a representational conclusion as a static image. They must not only put across the regulations for development but also depict a framework of future urban image.

Urban planning should be considered as spatial framework of the dynamic city. Contemporary urban design needs steer urban designers to use technological advances in urban modelling applications. In this point, procedural modeling (PM) steps up for aiding the design thinking process as simulation tools rather than means of final representation (Parish and Müller, 2001). Indeed, recently developing computer technologies such as PM are considered as useful tools for such urban planning tasks. Even two fields are originated from different perspectives, PM and urban planning has similar concepts in common. PM is defined as the group of tools that transform a simple input into complex structures using procedures. Urban planning defines the regulations for urban built environment instead of designing whole built environment in detail. Thus, instead of designing the entire content as a final product, both fields are intended to define a framework that creates the content.

PM represents a family of techniques for generating huge amount of geometries from a simple ruleset and a basic initial geometry. As a newly developing field of 3D city modeling, procedural modeling of cities has a practical history of two decades. Earliest works on PM provided a basic framework for this field and since then, practices on modeling urban areas have flourished.

This research is based on understanding of PM as a practical tool with the capabilities of generating multiple iterative urban frameworks that can be manipulated through variables and be shared. Generated iterations may have the potential to be constructed as the initial installed design framework, but it is the natural processes that flow through the framework that have the potential to bring together an evolving a “final design.”

1.1 Problem Definition

In this part, identified problems within the scope of this thesis are defined. Firstly, situation of rapidly-growing contemporary cities as well as new challenges that cities are facing today and will face in the future will be deliberated. Secondly, problems of current Turkish planning legislation both in terms of regulative aspects and within the scope of incorporation with novel tools will be summarized. Later, the lack and deficiencies of contemporary planning tools will be evaluated. Lastly, advantages of 3D modeling and the possibilities of 3D planning processes and the use of computerized tools in the design phase will be investigated.

1.1.1 Rapid urbanization and new challenges

World today, is in the midst of rapid urbanization. Today, urban areas host more than half of the world population. Cities are going to be build faster and faster. On the other hand, another challenging factor that cities are facing is pressing environmental issues. The parallels between man-made systems such as economy or infrastructure, or the complex natural systems are bringing new ideas with strategic planning and risk management. Pressing challenges for cities require new acts increasingly. Additionally, these demands are expected to be fast and efficient. Henceforward, cities are trying to find novel ways in order to be more and more resilient communities.

Moreover, dynamic relationships of the city make urban development unpredictable. This situation caused the search for new generative methods that enable designers guide the design process with the help of interactive control tools. New features are emerging in the subject of urban design such as interactivity and flexibility.

Considering that the way that urban planning will be employed and operated is going to change, future comprehensive plans will need huge amount of data. The way that planners will handle, manage and visualize this data is a matter of debate. New tools of planning are required to be able to create reasonable visions by considering the complex base information including formal, environmental, economic constraints. These tools, therefore, should be able to simplify and process those complex information to aid the designer.

1.1.2 Problems of Turkish planning system

Another pressing challenge that today’s spatial urban planning practices are facing is the regulative instability. Legal planning legislation in Turkey is ever-changing. Rules and statutes are changing day by day. Local development plans are modified by local administrations frequently. Likewise, the legislation shaping the urban development on whole country are changing by the central government. To keep in step with such regulation changes is a challenging task for both public intuitions and private corporations.

Additionally, in spite of this ever-changing system, planning legislation in Turkey have a poor relation with technological advancements. Although there are recent minor regulations to store and manage GIS based plans (Ministry of Environment and Urbanisation, 2011), these efforts slightly fall behind the contemporary technologies in practice. Yet, public enterprises uncommonly started to ask for more complicated submissions in project approval processes. Although it is not a common legal responsibility, some public enterprises lay down condition new entities such as GIS data, realistic renderings or digital 3D models in urban design or architectural project submissions.

On the other hand, urban planning processes are hardly producing well-analyzed outputs. It is apparent that most of the adopted development plans do not have an explicit spatial strategy. Indeed, three-dimensional aspects of city plans are rarely considered. Instead, the mechanical calculations of construction areas are the chief point in plans, mostly.

The role of emerging construction sector in Turkey has a significant role in this point. Since the cities in Turkey are expanding very fast, urban land has become one most profitable assets in the economy of the country. Increasing speculative economic gains have led the construction sector to expand beyond measure. Thus, urban planning is under constant pressure of this sector. Most of the decisions on the urban land lack professional opinion since decision-makers and technical professionals are manipulated by constraining situations. Hence, spatial decisions are mostly considered as with their effects on the speculative economic gains instead of the effects on the livability of the built environment.

On the other hand, emerging technologies are continuously creating new interfaces for information sharing. Main concern behind this research is the need for identification of these new interfaces that planning or urban design projects will face in the future. In order to conduct efficient analyses and manage responsible planning processes, it will be necessary for planners to be familiar with these interfaces in the future. As a widely accepted fact, 3D visualizations are evaluated as more reliable than traditional representations as they make the spatial data more intelligible (van Lammeren et al., 2010).

1.1.3 Problems of conventional planning tools

In order to envision future of planning, current situation has to be analyzed, initially. Traditional approaches to urban planning offer a fixed final product. Contemporary and future cities cannot be envisioned by these stationary tools and techniques. Conventional planning language is based on two-dimensional (2D) development or zoning plans. Typically, development plans are prepared as 2D maps that do not have three-dimensional aspects. Yet, conventional plans have difficulties in expressing vertical dimension of the area. Such situation also hinders planners from imaginative thinking in planning process. Therefore, produced plans mostly lack of design content (Al-Douri, 2006).

Al-Douri (2006) has approached to this issue as grouping problems into three categories; information-related problems, communication-related problems and representation-related problems. Firstly, there are overwhelming volume of information pertinent to the design problems. Poor management and insufficient analysis of data leads to wrong design decisions. There is a need for development of new techniques to interact and manage huge data of contemporary and future cities. Secondly, communication related problems are due to planners' or designers' inability to communicate by efficient visualizations. This situation leads to discussing design concepts and strategies in limited mediums such as 2D. Representation related problems are arising from lack of interactivity such as in conventional presentations. Plans lack of necessary informative content as in the way that is easily perceivable by the general public.

Urban planners abstain from using 3D tools, since such tools are relatively complex and planners do not have required skills for utilizing these tools in daily planning operations. Conventional plans significantly limit analytical thinking of planners. Thereby, poor urban environments and plans produced by only formalistic concerns for complex cities, provide evidence for such limitations (Lee and Kwan, 2005; Xie and Batty, 2003). In addition, there have been very few efforts that seek to integrate them also with other technologies such as GIS and the Internet (Huang, Jiang, and Hui 2001 p.441). Those approaches should be increasingly integrated with urban planning in order to produce more responsible plans for tomorrow's efficient, complex and resilient cities (Xu et al. 2009).

1.1.4 Advantage of 3D plans

Spatial urban plans are intended to regulate the future development of cities. Planning is focused on the relationship between urban elements within a coherent functional and visual structure. Therefore, they need to visualize the environment that they envision. Computational plans have proven to have higher level of design framework (Al-Douri, 2006). Functions of the models can be used effectively to improve decision-making processes. They provide a communication platform for exchanging design ideas. Modeling of urban environments are useful in many viewpoints (Watson et al., 2008). Their primary usage is as communication tools in various cases i.e. political decision making. Using tools such as PM, it is possible to make conventional 2D plans to be more visually understandable by professionals and other stakeholders in planning and urban design practices. They also provide a guidance for design projects in particular areas. By employing novel computer technologies, depicting the impacts of alternative planning policy scenarios is possible. Visual prediction of land use policies and their effect on existing developments gives a great chance to observe the future of a particular urban space (Barredo and Demicheli, 2003).

Urban planning and design process requires collaborative approach between multiple disciplines. The team working on a planning or urban design may consist of various professionals and non-professionals such as urban planners, architects, landscape architects, sociologists, geographers, engineers or public. All of these parties may approach the design from different viewpoints. All stakeholders have different design criteria and might be in need of different visual representations. 3D models are proved to provide a common ground for all of the parties. Besides, city models are no longer intended to be prepared for only visual concerns, instead they can carry GIS-based information which is preferred by professionals.

1.1.5 Design with machines

As new technologies are developing, machine-learning techniques are increasingly researched. Human workload is gradually decreasing in computer-aided design field in the last decades. Technologies such as automatic data processing, management and manipulation are offering valuable assistances for designers. In fact, designers need to let the machines do some part of the design process. Yet, ways to distribute the workload of this process among machine and designer are being researched (Koenig and Schmitt, 2016).

These new research fields will enhance cognitive design computing in future without doubt. Tools that give designer immediate feedback about the design decisions are already used as control tools. The balance between automated design and user controlled assistance would be a useful equilibrium for computer-aided design practice.

1.2 The Aim of Study

New information technologies such as 3D urban models, web-based communication systems and new media interfaces can improve the final products of urban planning. These technologies are becoming necessities rather than optional additions. Indeed, these tools make it necessary to develop new design methodologies which are augmented with such effective support tools. This study offers an approach to eliminate possible loss of information in a plan could deliver reliable and accurate validation opportunities by use of technological advances in urban modeling tools. Then the case study includes creation of a dynamic 3D urban model, having procedural codes as information holders. Further, the model, will be deliberated with its possible uses in urban planning and design processes.

Conventional 2D plans regardless of scale are inadequate to illustrate intended layout of the city. The goal of this thesis is to understand and show how the usage of PM tools may improve a responsive design approach into implementation plans and urban design products.

The research will address two primary questions. First question is whether 3D urban models can really visualize possible alternatives of the urban environments that a current plan regulates or not. The study will conduct case scenarios to query if procedural modelling technologies pave the way for looking at the urban space more comprehensively than its current 2D form. Second question is whether previously-mentioned rapidly ever-changing legislation system in Turkey can be integrated into 3D-GIS based PM as one of the new technology. In this context, this study aims to examine whether the spatial parameters and tools that Turkish planning legislation defines work efficiently when integrated with PM techniques plan new development sites.

1.3 Hypothesis

This thesis is guided by a central hypothesis that urban planning processes should include usage of 3D urban models. If a PM structure that adhere to planning regulations would be created, such system can enable a design-oriented planning process. Secondly, urban planning would be efficiently reinforced with harmonious design aspects. Indeed, this framework can be designed to visualize a realistic description and evaluation of urban environment within this regulation-defined boundaries.

New technologies such as PM can help make better plans. This system can be integrated with Turkish planning system in order to visualize plans and examine their features in 3D. Since procedural city models are integrated with GIS-based information and internet communication systems, they provide valid communication and data management tools. As they are capable to be integrated with flexible databases, they may help to interact with large urban datasets and 3D information, effectively.

1.4 Methodology and Structure of Thesis

As mentioned before, planning system is ever-changing. Since this dynamic legislation increasingly adds new regulative codes, the tools and means of regulation is getting more complex. To anticipate the consequences of this legal framework is difficult. Since there are many confusing parameters within legal codes, it is difficult to foreseen the planned outcomes. In this study, a methodological approach is adopted to simulate city model in a case area that is employed to depict in current plan and its legal appendix. This model includes GIS based data which the user can make a query to see its full attribute data.

The system defined in this study, aims to portray the environment that development plans define. An algorithm is written by transforming spatial parameters into procedural parameters. This algorithm is used for creating 3D models in a case area by using current implementation plan as the base departure point.

PM enables modeler to define the parameters of plan regulations, to provide randomness to these parameters within the regulative limits that plan depicts. For example, if the plan restricts the maximum floors and the total floor area ratio, other parameters such as setbacks, coverage or building width and depth could be randomized or edited.

Methodological approach of this study is structured as in three phases. Firstly, a literature review which focused on reviewing secondary sources to construct theoretical propositions about the impact of digital procedural modeling on urban design is conducted. This review is focused on three main subjects; GIS, 3D urban modeling and procedural modeling.

Secondly, a preliminary study is employed for integrating the spatial tools that Turkish planning legislation has defined. For the modeling objectives, a PM tool named CityEngine (CE) is used. By using the software, new algorithms are created in order to construct an operational pipeline for the software to process the modeling. This pipeline has used parameters of spatial tools of legislation.

CE provides rapid design and visual implementation of planning ideas. At the same time, it enhances methods of communication towards accessible 3D solutions. CityEngine today, hosts various procedural techniques which are appended in the course of time. CE employs procedural rules as the main algorithms that utilize the modeling operations. One of the most crucial aspects of PM in CE is that as well as input geometries, procedural rules are also required to be provided by the user. Hence, instead of fixed operational tools, users can define their own algorithms to create models. Procedural rules also enable user to consider and create real-time reports with vital information during the planning process.

As a final step, prepared algorithms are employed for the creation of 3D models of development plans for an area. Although there are infinite number of design alternatives that a plan offers, this system will act as a framework. After this framework is constituted it is possible to generate design alternatives randomly. However, an empirical approach is developed since all of those random alternatives cannot be represented and analyzed in this thesis.

By considering this process as an urban design project, two alternative design approaches are defined with certain criteria. Then, according to criteria of these alternative approaches, parcels in case study area is modeled by interactively editing the parameters. Since the procedural algorithm is written accordingly, both models are in comply with the regulations in parcel level. After that, reports are conducted in order to evaluate numerical analyses of the models. By comparing those reports, quantitative differences between two models will be examined.

This chapter was a brief introduction to the definition of the problem, the aim of the study and the structure of the thesis. As previously mentioned, today's global world is creating variety of challenges for cities. Future or urban planning is expected to be shifted such as increasing new demands of cities. Yet, conventional urban planning and design tools are not capable of handling the design content as a whole. Novel techniques offer a shift in the approach to complex design problems. In the next chapter, research and developments on those novel techniques will be reviewed in detail.

2. GEOGRAPHIC INFORMATION SYSTEMS AND 3D PROCEDURAL MODELING

This chapter focuses on deep literature investigation covering three main fields; geographical information systems (GIS), 3D modeling and procedural modeling (PM). Initially, emergence of GIS as a technology to aid various fields and its contemporary usage will be covered. Later on, the place of this technology as a supportive tool in the field of planning will be deliberated. Technological developments are increasingly offering new opportunities in the field of spatial information systems. Recent researches on the integration of GIS with new phenomena such as 3D visualizations or world-wide-web will be investigated.

On the other hand, research and applications on three-dimensional urban modeling will be reported. As a popular research and application field, 3D modeling is widely used in visualization of urban areas. 3D models are used in variety of cases, from basic visual concerns to detailed analysis. Later, different types of 3D modeling will be discussed in detail. In particular, the differences within the means that drive to end product in modeling will be deliberated.

Thereafter conventional and emerging modeling techniques are introduced, findings on PM will be reported. Even though this field has a short history in urban context, procedural approach in city modeling have great potentials to become one of the mainstream methods. Following, main concept and applications of the technique will be examined. CityEngine, a PM tool which will be used in case study will be utilized. Additionally, similar studies conducted on this tool are reported.

2.1 Geographical Information Systems (GIS)

Cartographic products have been used for a long time. Traditional cartographic maps were static images that include geographical information but they do not have a *system* involved. Eventually, digital mapping is developed and producing geographical information consequently transformed from a system maintained manually, into a system maintained by computers.

GIS is not only the process of producing maps, but also management of the spatial information, analyzing it and rendering the results into maps. GIS today, is designed to capture, store, manipulate, analyze, manage and represent all types of spatial data. The integration of GIS with other technologies such as internet is a huge leap forward in this field. There has been an explosion of mapping applications on the web. Today, general public is exceedingly involved with huge amount of geographical data in daily life.

2.1.1 History of GIS

GIS is being researched and developed since 1960's. As one of the most cited works in this field; McHarg's (1969) *Design with Nature* presented a method for analysis by aligning various sheets of paper on top of each other. This analogous method guided to the storage and manipulation of digital mapping technologies. First ever known use of Geographic Information Systems as a term, is in Tomlinson's (1969) paper; based on the work that employs computers to automate mapping land inventory in Canada (Tomlinson, 1962). Initially, it was an environmental technology at first, used for mapping and land suitability analysis (Drummond and French, 2008). With the development of technology and spread of computers, physical methods on geography slightly converted into computer-based systems. As the computer graphics are evolving with innovative solutions such as raster and vector approaches, GIS started to be used by limited number of users such as governmental organizations. By the early 1990s, GIS have become widely commercialized by variety of professional software like every field related to computer-graphics.

Today, GIS is automated, dynamic and socialized more than ever. Novel data acquisition technologies ease the process of providing raw data. Automatic data processing enables human workload to decrease at appreciable levels. As general public is also involved in GIS applications by the help of worldwide web, GIS has become more social, more interactive and less self-enclosed.

2.1.2 Utilities and the usage of GIS

GIS is a geographical system for capturing, storing, manipulating, analyzing and representing spatial data in layers (Figure 2.1). It is a broad, umbrella term for all techniques facilitating preparation and interpretation of data which is geographically referenced data. It is a tool for handling spatial data by combining external geographic data such as quantitative databases or georeferenced maps. With the help of GIS, the user can interconnect the exterior data with the geo-spatial entities. It is designed to capture, store, update, manipulate, analyze and display geographically referenced information and associated quantitative attribute data (Tang and Waters, 2005).

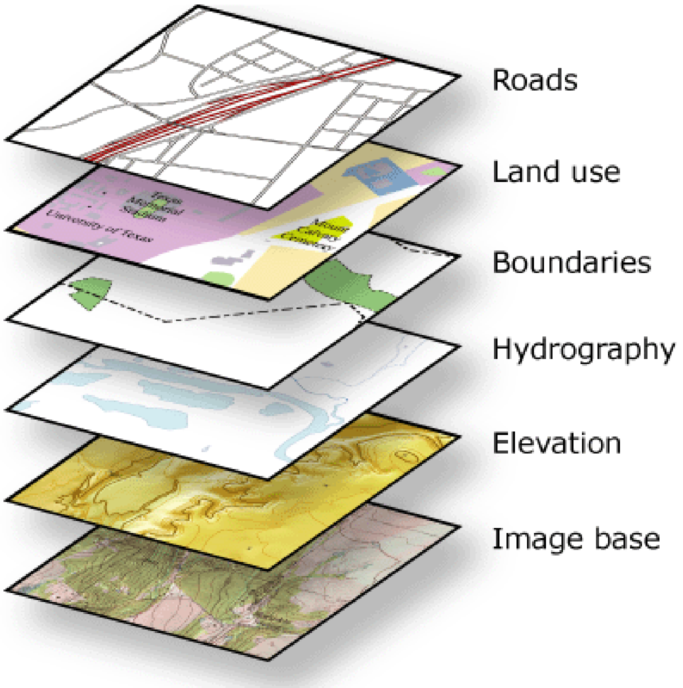


Figure 2.1 : Layered system of GIS ("What are map projections?", 2016).

A wide variety of disciplines are involved in GIS for various tasks. The field of geography is one of the initial disciplines that has long history with spatial analysis. Cartography, remote sensing, photogrammetry and surveying, as well as mathematics, statistics and computer science are some of the main disciplines that both contribute and make use of GIS.

GIS technology has a wide range of application areas. One can found numerous application examples in academic sources and commercial practices. Some of the important areas that GIS is being used listed by Fazal (2008). One of the major use areas is planning including urban, transportation planning and landscape and urban design cases. Street network based applications serve navigation purposes by making use of vehicle routing, location and address based site selection. Management and analysis of natural resources are also an important area of use. Land acquisition and ownership management cases are also a common area. Lastly, management of man-made artifacts such as pipelines and energy lines is worth to mentioning.

There are variety of forms of utilization within previously listed fields. One of the main uses of GIS is database management. GIS can store data in multiple databases and in various types of geometries. The common feature dataset forms that used in geographical information systems are points, polylines and polygons. Visualization is one of the main uses of GIS. Better access to maps, improved mapping techniques, better thematic mapping possibilities brings better understanding of environment. Spatial analysis includes procedures and tools to analyze complex relationships of geo-referenced data. It allows performing geoprocessing functions such as map overlay, buffering and connectivity analysis in its purest form (Yeh, 1999). Spatial modeling is a useful function of GIS to predict the impacts of existing statistical trends. Modeling different spatial scenarios helps guide future developments and decisions.

GIS software has powerful functions and tools to aid related disciplines. In performing a systematical spatial workflow in any discipline, GIS can play a crucial role. Procedural modeling which is the subject of this thesis, uses automated functions of GIS to enhance semantic capabilities of produced models.

2.1.3 GIS and urban planning

Today, GIS is an indisputable tool in the mainstream planning practice. GIS is used as a spatial information database and a decision support tool by urban planners. The fact remains that emerging technologies allow planners use GIS in varied ways. Since the cities are complex organisms, need for accurate data management becomes a crucial point in the sense of GIS. Planning the future of cities requires scientifically tested scenarios based on reliable data. GIS as a whole, is proved to be a crucial system for supporting planning processes.

Most planning works have been including spatial analysis and modelling for a long time (Batty, 1976). Hence, with the help of GIS, spatial statistical analysis which is useful while analyzing the spatial character of the area plays a crucial role. The automated tools of GIS provide better decision support for site selections. Plenty of researches (Liu et al., 2007; Sante-Riveira et al., 2008; Stewart and Janssen, 2014) show that GIS is useful in land suitability analysis or land use modelling and assessment of spatial decisions. Moreover, interpolation, map overlay, buffering, and connectivity measurement are the most frequently used GIS functions in spatial analysis and modelling (Yeh, 1999).

Reliable and accurate information about the city and inhabitants are the key base information for development and management of the city. GIS helps to make this process automated since it is able to aid the process of gathering data and conducting geospatial analyses. Collecting data in the resource indexing refers to creating a database in GIS terminology. The data required in planning process is mostly georeferenced information. Variety of information is required in planning analysis such as environmental, land use or statistical data. Technological developments such as remote sensing (Xiao et al., 2006), photogrammetry (Döllner et al., 2006; Singh et al., 2013) and social-based techniques such as crowdsourcing (Brabham, 2009) refers to increase the efficiency in data collection. Remote sensing and photogrammetry technologies become more important day by day as they significantly save huge amount of time and bring accurate live information about the land. Addition of crowd-sourced data into GIS also give considerable amount of richness to the GIS data.

One of the basic duties in GIS is map overlay of various geographical data. Variety of data such as economic, social and physical data of the city can be stored in GIS. Yet, once the GIS has the essential data, analysis of existing situation may be conducted in GIS. Mapping tools and various query techniques can be used for manipulating and analyzing these datasets. GIS helps to analyze the overlapped information to see the areas of correspondence or confliction. These analyses may be subject of various environmental, social or physical inputs.

Besides analyzing the current situation, planning deals with the future situations. Indeed, modelling and projecting is essential to the urban plans (Longley et al., 1994). Statistical data of population, economy and environment can be estimated in GIS. Various scenarios can be modelled in GIS based on different projections. In the projection and spatial modelling phase, objectives and actions are essential. General objectives of the plan are directly associated with its estimates. Range of scenarios may be simulated to justify the planning decisions (Landis, 1995). Hence, all kinds of statistical data can be projected. Future demands for spatial resources can be analyzed through projections of socioeconomic and physical data.

Practices show that GIS becomes more useful when it is used in various other tasks besides plan drawing. Geographic information systems are useful in testing the impacts of spatial decisions. However, not all the geoinformation tools are efficient to be used in process of spatial planning since they have a generic nature (Klosterman, 1997). This deficiency give rise to emergence of advanced systems to extend GIS functions by visualization to support planning process.

Planning decisions are made according to various factors. In a typical process, having done the necessary analysis, urban planners put forward planning options. Planning support systems (PSS) are introduced as an integrated framework to gather information technologies used in planning processes. Development of planning support systems help GIS to be used also in management activities such as land parcel mapping, permit tracking, zoning (Drummond and French, 2008) or environmental influences (Yeo et al., 2013). According to suitability maps, GIS can support development of planning decisions. Variety of researches show that planning support systems aid the process of decision-making (Brail and Klosterman, 2001; Geertman and Stillwell, 2012; Harris and Batty, 1993; Klosterman, 1997).

Global cities of today are growing and changing rapidly. Accordingly, planning practice has many stages since it is an ongoing process. GIS serves differently in each planning stage; different scales and types of planning require different GIS tools (Yeh, 1999). The different stages in the urban planning process are listed as; objective determination, resource inventory, situation analysis, modelling and projection, development of planning options, selection of planning options, plan implementation, and evaluation, monitoring, and feedback. According to Yeh (1999) in the beginning of the process, for example cognitive stages like developing vision and objectives; GIS is insignificant. It is more useful in modeling and development of planning scenarios. Different functions of urban modeling require different GIS components. Tools like data management, visualization and spatial analysis are used in general routine of planning. In strategic planning cases, spatial modeling is used more. Data management and visualization are used in general administration functions. In the case of development control, spatial analysis steps up.

GIS is extensively used in developed world by urban planners for planning and detailed analysis using 2D maps. They enable planners to overlay spatial data, which can then be used to effectively analyze and manage the decisions on urban spaces

(Ahmed and Sekar, 2014; Evans et al., 2001). Utilization of conventional GIS is dispersed around different planning stages. In the following sections, novel approaches in GIS that enhances its interactivity and efficiency will be reviewed.

2.1.4 3D GIS

Since last three decades, emerging computer technologies enable cartographical techniques to evolve in various directions. Using conventional 2D methods of GIS to represent urban areas has shortages since it ignores 3rd dimension of the real world (Evans et al., 2001). One of the considerable steps that GIS technologies have achieved is 3D GIS. Using 2D GIS data, highly detailed 3D representations can be made. Yet, using only conventional planning tools, is not efficient for urban planners to put a vision to fast developing cities (Ahmed and Sekar, 2014).

Transforming 2D data to be used in 3D GIS environment gives the ability to represent the environment for better understanding. GIS-based 3D models enable efficient description of spatial objects such as buildings, terrains and natural or man-made entities. This three-dimensional workspace ensures a workspace for planners to observe the impacts of their decisions on surrounding area. The decisions that planners make should be based on the consideration of the area in its full spatial extent (Evans et al., 2001).

3D GIS is used for visibility analysis urban planning, field of geography, geology, civil engineering, ecology, meteorology, hydrology (Abdul-Rahman and Pilouk, 2007) and in architecture (Landeschi et al., 2016). It is also a better tool for environmental analysis such as shadowing, ventilation, storm simulations, lighting (Kaufman, 2014) etc. Since the environmental factors are one of the top concerns of today’s cities, ecological factors such as noise, air, energy, pollution and climate are a must to be included in any analysis conducted in urban space. 3D GIS provides solid tools to visually analyze all of these factors effectively.

3D GIS is highly commercialized in use by the utilization of GPS navigation devices. Actually, they may be considered as 2.5D rather than 3D (Edvardsson, 2013). Most of the navigation tools include basic elements of city such as roads and buildings. They provide 3D look by extruding buildings and tilting the scene. However, they provide a crucial service to general public in wayfinding with frequently-updating databases.

Traditional 2D mapping applications in any field, reduce the spatial description of real world objects. By using 3D applications, the reality can be interpreted in digital environment. Usage of 3D GIS-based visualization systems, enables the planner and different actors assess the outcomes of the spatial decisions long before realization (Bartel and Köninger, 1998).

2.1.5 Integration with internet

Current technological developments enable GIS to be involved by almost everybody. At the beginnings of evolution of GIS, it was only used by specific professionals such as urban planners, geographers, academicians or associated decision makers. However, rapid developments in technology provide new ways to bring together GIS and Web. Recent advancements in these fields provide opportunities to invent new tools that strengthen social interactions. These tools use GIS in new ways rather than traditional approaches such as spatial analysis, but in producing new content to be used in public interaction (Bugs et al., 2010).

Internet-based systems were already proved to widen participation levels (Al-Kodmany, 1999). Especially in the large communities that it can be difficult for people to participate at particular time and place, internet-based information systems are employed for a long time as a useful tool (Kingston et al., 2000). Incorporation with various community forms triggered a tangible shift in GIS to be more socially aware (Dunn, 2007). As one of the implications, the term Public Participatory GIS (PPGIS) is emerged in late 1990's. Since then, GIS has become more interactive than its traditional form. There are numerous case studies that prove the efficiency of web-based GIS applications (Aye et al., 2015; Brovelli et al., 2015; Brown and Weber, 2012; Marsden, 2015; Wolf et al., 2015). This technological evolution that involves stakeholders is likely to provide a way forward in achieving sustainable development (Bugs et al., 2010).

Web 2.0 has brought new opportunities, just as web-based GIS applications that are used to publish planners' work and collect feedback on the work. Web 2.0 is considered as the current state of internet technology that is defined by excessive user interactivity and collaboration. In contrast to first generation of websites which users are only viewing to content in a passive position, Web 2.0 has brought a dynamic relationship between people where every individual is allowed to create content in the web. Social networking and social media, blogs, video sharing sites, web applications, collaborative platforms are examples of such technology. Web based GIS enable non-professionals to participate in professional processes. Before the widespread usage of 3D technologies, web-based participation techniques were structured with 2D maps, images or sketches (Wu et al., 2010). With the help of 3D technologies combined with emerging communication technologies, very sophisticated urban simulation systems can be constituted. Using internet computation techniques, dynamic environments can be interactively visualized (B. Huang, 2003).

Professional GIS tools are also turning into web. They offer collaborative web GIS applications that are used to create and share all kinds of spatial data online. Supported by secure cloud systems, publishing and simultaneous data sharing have become the popular features of web GIS. These applications are accessible though web browsers, mobile devices as well as desktop software, so that information sharing is easily operated in maximum number of platforms.

Along with professional software providers, applications for general public are also flourishing. Since major internet companies get into the field of map providing, GIS has been available directly in mass consumer market. Web-based mapping tools such as Google Maps, ESRI Maps or Microsoft's Bing Maps are transforming the way that GIS is utilized and enhancing the public usage of spatial information (Klosterman, 2008). They are becoming more and more information-rich. Not only they provide advanced information on spatial basis, but also they allow individuals to share spatial content over these services. Users can display data, measure distance as well as areas, add placemarks and annotations on these mapping applications. However, sophisticated tools like simulation, modelling and spatial analysis are still not easily usable by non-professionals.

A great number of mobile applications, web-based services use the combination of GPS, GIS and wireless technology to collect and publish data. They can be integrated with plenty of mobile applications since mobile devices can be used to acquire geographic knowledge and transmit it to the online systems (Brovelli et al., 2013, 2015). According to Drummond and French (2008) Web 2.0-based GIS applications are stretching the definition of GIS and show that interactive nature of web is reshaping the ways we view and represent space.

As mentioned before, GIS deals with management, integration, processing, analysis and visualization of spatial data. Day by day, GIS is becoming more crucial for urban planning since it becomes more integrated with Internet, visualization and 3D modelling. Urban planning processes are prominently improved by information technology fields (Doyle et al., 1998) and it is becoming more interactive.

2.2 Three-Dimensional Modelling

There is a growing popularity of 3D modeling of large urban areas nowadays. Since wide variety of usage areas are also flourishing, the popularity of this field increases (Shiode, 2001). One of the prominent usage areas of 3D models is architecture and urban design. Today's master planning projects in global world require designers to create digital content. However, 3D modeling has a much wider application area including planning, engineering, archeology, medical, entertainment and many other fields. More and more fields will require 3D models with higher accuracy and improved techniques in near future (Luan et al., 2008).

New technologies on photogrammetry, remote sensing or procedural modeling approaches provide opportunities for creating huge 3D scenes faster than ever. On the other hand, recent advancements in communication technologies provide new interfaces for communication (Cirulis and Brigmanis, 2013). In the light of this information, it is not hard to estimate 3D modeling will have more automated creation pipelines and much wider area of application in the future.

One of the reasons for 3D digital modeling is popular may be they help designers to experiment with their design ideas and to increase imagination levels. Therefore, designers can facilitate a participatory design process by fast exploration of alternative concepts (Al-Douri, 2006). Other than design purposes, entertainment industries increasingly use 3D virtual content in movies, games and so on. In fact, gaming and entertainment industry was considered as the main driving reason behind 3D content generation.

Along with the rise of technologies such as augmented reality (AR) and virtual reality (VR), extensive need for 3D models will be faced. Augmented reality (Figure 2.2) stands for the technology "that allows users to see the real world, with virtual objects superimposed upon or composited with the real world" with the help of mobile devices or head-mounted displays (Azuma, 1997). VR (Figure 2.3) is a simulated environment that is experienced via head mounted goggles and interacted in 3D with the help of wired clothing (Steuer, 1992). Today, such technologies are increasingly used in different cases. Therefore, applications on variety of fields need to construct digital cities more than ever. Indeed, future city models seems to be required as more and more compatible with interactive interfaces.

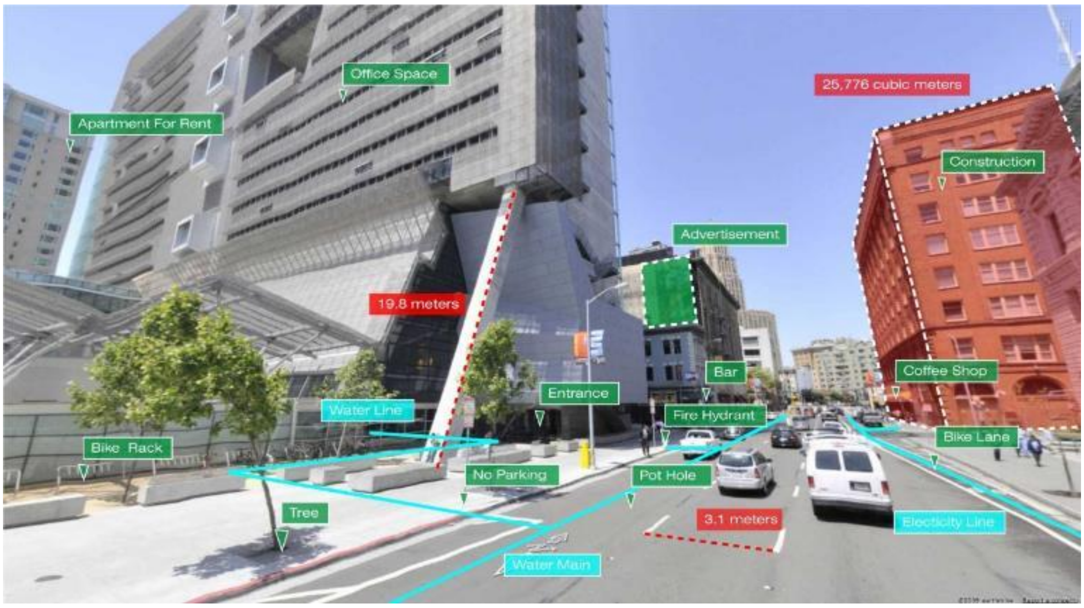


Figure 2.2 : Augmented reality is used with GIS-based data in cities (Maggie Talal, 2014).

Figure 2.3 : VR is used in different fields (Clayton Purdom, n.d.)

2.2.1 3D city modeling

Urban environments were represented in 3D with different elements in real models by hand for a long time. Both current situation or design proposals were being modeled by using different materials, with enormous handwork. Nowadays, real city models can still be considered as useful since no matter how new interfaces have emerged, physical models are considered to give better perception than computer generated models. Indeed, computer based modeling tools are used in the process of physical model creation. Yet, computer technologies offer a lot of techniques to visualize cities in 3D forms. Creative presentation techniques combining physical models and digital augmentation techniques can be found populously.

To date, both techniques and means of presentation of city models have changed. In former applications of city modeling, outputs of GIS were limited. A traditional method is to produce static renderings as outputs. Recent advancements in computing have enabled new interfaces to interact virtual city models (Morton et al., 2012). Today, through web-based interfaces, maps or 3D GIS contents can be presented as interactive applications. Thus, means of city model creation are also changing.

One of the main objectives of 3D city models is visualization. 3D city models are proved to provide a refinement on 2D data. Since technical drawings create a common ground for communication for architecture, urban design and planning professionals, 3D visuals give an augmented perception for everyone. 3D architectural visualizations are enormously used for advertising and presenting the project. 3D visualizations help to facilitate feedback of public opinion and create a public awareness. Good representations also used to attract developers and guide other designers to be informed about the project.

Besides pure visualization purposes, 3D city models are also used as information carriers. As they are visually easier and faster to understand, they have the ability to conceive more detailed information than 2D graphics. As previously stated, integration of GIS with 3D modeling process have enabled city models to contain and convey information. For storing, managing and exchanging large scale spatial data, new standards are being defined such as CityGML. It is defined as a unified model for storing and exchanging 3D city models (Kolbe et al., 2005). It includes not only a graphical content but also semantic and thematic attributes inside. Multiple types of representations in different level of detail are possible with these types of data containers (Döllner et al., 2006; Malinverni and Tassetti, 2013). As an example in architectural scale, Building Information Models (BIM) stands for a technique that stores the needed information related to building and can manage detailed construction-related information of a building. The integration of such techniques coupled with GIS, enables performing an extensive range of analyses (Rua et al., 2013).

Applications of 3D city models have been categorized by Biljecki et al. (2015) according to uses cases within several application domains. They have reviewed recent state of art in the field of 3D urban modeling. Works are categorized into two groups where visualization is the main criteria. (1) The cases, which are created as a result of spatial operations and of which the visualization of the results is not necessary, are classified as non-visualization cases. Some of non-visualization based cases include estimation of solar irradiation, energy demand estimation (Figure 2.4), determination of floor space and classifying building types. (2) The cases, which require visualization as the main purpose of creation is to communicate urban information and virtual reality, are grouped as visualization-based cases. Common use cases in this group is design-based purposes, real estate, obtaining panoramic views, web visualization, thematic mapping, gaming and augmented reality. 3D city models mostly have been used as a tool for visual demonstration in the last decades.

As previously mentioned, urban models are being operated as more than only representative concerns but in several other fields. Although visualization is the main concern, it is mostly combined with the enhancement of the presentation of results of an information-based process. To count some in this category, most relevant issues are natural analysis such as visibility, shadow casting, estimation of seismic damage (Figure 2.5) and flooding, forest management. Also estimation of effects of man-made environment such as noise and lighting falls into the same group. Navigation and routing can be added as the most commercialized use cases. Representation of social attributes such as demography and economy can be also mentioned. Archeology, 3D cadastre and urban planning are the last but not least categories.

Large-scale urban models are becoming more popular in both practice and research fields day by day. As commercial entity, city models are demanded by various fields including gaming, movies, urban planning and navigation systems.

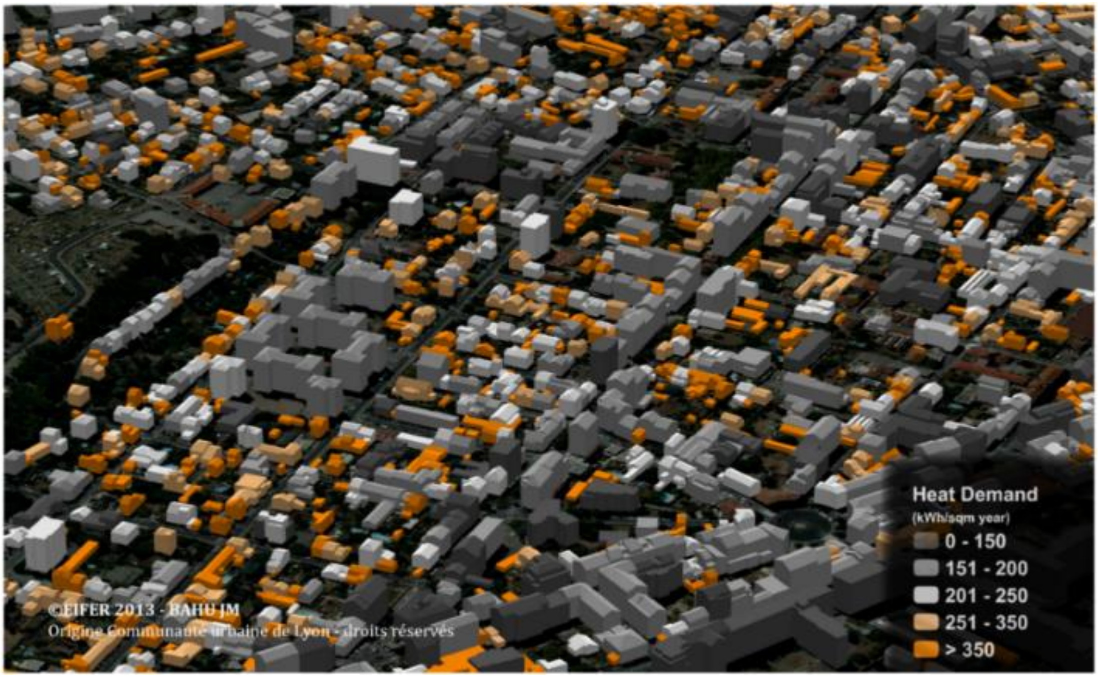


Figure 2.4 : Visualization of energy demand estimation (Biljecki et al., 2015).

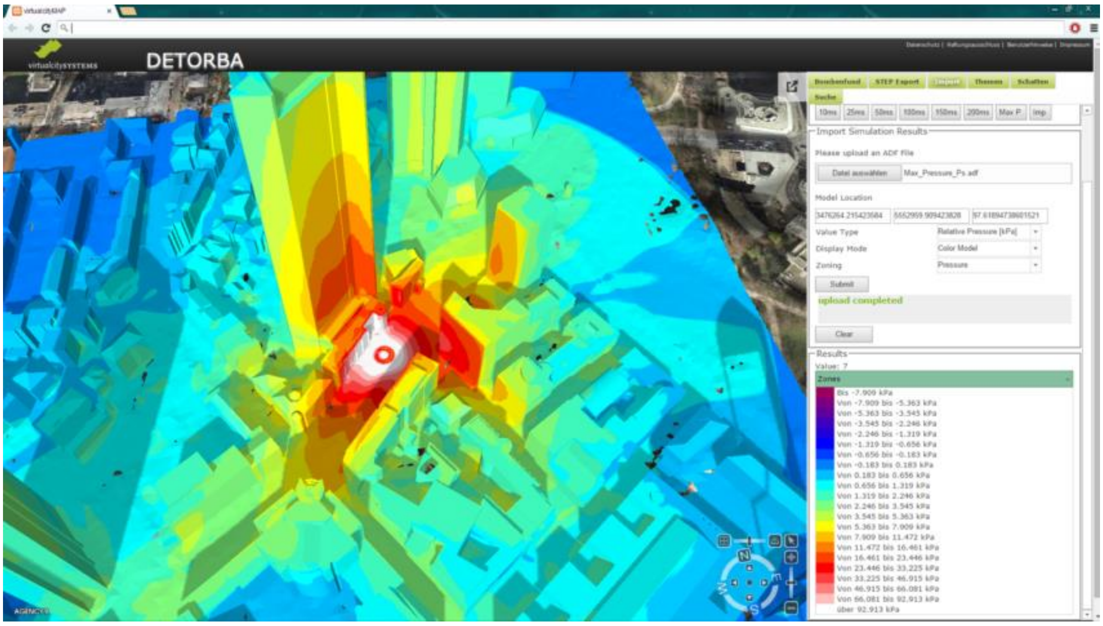


Figure 2.5 : Simulation of bomb explosion in urban area (Biljecki et al., 2015).

2.2.2 Types of modeling

Visualization in planning and design fields requires a balance between abstraction, accuracy and realism. Under different circumstances, level of abstraction of 3D city models should need to be changed (Figure 2.6). Intended output should have an acceptable visual quality but avoiding unnecessary costs. An ideal 3D modeling case should be in a feasible equilibrium (Pietsch, 2000). Majority of city models consist of low-detailed buildings with lack of semantics (Divya Udayan, 2016). It gives a good image when viewed from long distances, but they do not work if viewed in human scale.

There are various techniques and tools to create any computer generated content. Traditional modelling has advantages in terms of representation and consistency. Use of manual modelling tools gives the ability to create realistic visions. Tools such as 3dsMax and SketchUp are cost-effective on small scales and better visual outcomes, but they lack informative content. Manual methods are started to be abandoned since it is costlier than procedural methods.

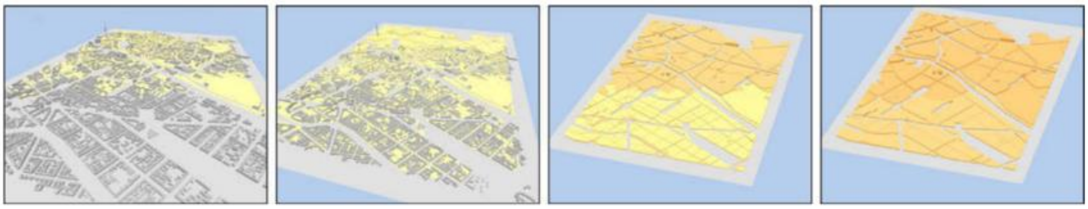


Figure 2.6 : Glander and Döllner's automated technique on transitions between various precomputed representations (2009).

Various techniques are employed to create 3D models. As Biljecki et al. (2015) report, these techniques may be listed as follows: photogrammetry and laser scanning, extrusion from 2D footprints, synthetic aperture radar, architectural 2D drawings, handheld devices, procedural modeling and volunteered geoinformation.

Traditional methods of modeling big scenes usually create satisfactory results. However, traditional methods used until mid-2000's are gradually disappearing (Vanegas et al., 2012). Instead, procedural modeling is stepping up as a cost-effective solution for commercial model producers. It offers a variety of content with very limited intervention (Smelik et al., 2014). One of the reasons that these industries are abandoning manual modeling is that it is time and budget consuming. Additionally, city models are required in bigger scales, nowadays. For example, open-world paradigm of contemporary video-games requires huge-scale urban models (Martinović, 2015).

Since the cities getting bigger day by day, the context of design processes is also getting more complex. Smart cities and sustainable future concepts are creating the need for using new ways to handle the urban space more effectively. As the comprehensive and data-based approaches step up in design processes, conventional modelling techniques starts to give place to more iterative tools.

2.2.2.1 Specification of techniques

Literature scan on acquisition of 3D models spread over a wide range of techniques. Literature review shows that techniques on modeling differ in terms of initial purpose of model's usage. Reviewed researches show that modeling techniques are distinguished into two groups. First, applications on reconstructing the current reality will be reported. Second, applications conducted in order to model out a new design will be reported. There are distinct differences between two groups of efforts in the data acquisition and processing methods. Modeling the current form of the city requires lot of data collection which can be acquired by various techniques. User mostly manages the data and the modeling pipeline in these situations. If the model is created for the visualization of a design idea, intervention of user is in high levels.

Most of the researches in the field of 3D modeling, are actually on modeling the current form of the city (Döllner et al., 2006). Not necessarily but mostly, for modeling reality, automated data acquisition techniques are used. Manual polygonal mesh modeling tools can be both used for modeling a real object or a new design.

2.2.2.2 Techniques to model current city form

Techniques and software for 3D city modeling were being researched and applied for a long time now. New computer hardware technologies enable everyone to have the hardware to be able to model urban areas. Modeling real objects is mostly a question of object scanning techniques. With the necessary data available, process of modeling city can become mostly automated. However, human-intervention is still needed to manage and refine the modeling process in any case. These techniques can be considered as digital reconstruction.

Acquisition techniques for 3D models is a matter of debate. Automatic and semi-automatic data acquisition methods have been researching for a long time now (Förstner, 1999). Technologies such as photogrammetry and laser scanners offer cost-efficient solutions especially when combined with digital terrain models (DTM) (Lang, 2007). There are methods emerging with new technology, such as Light Detection and Ranging (LIDAR) scanning, laser-based scanning that create a point cloud data.

Model-based approaches to 3D building extraction from various sources of data such as aerial images (Fischer et al., 1997) are being researched for a long time now. For example, terrestrial images are the images taken on ground level. In multi-sensor method, a 3D range laser and omnidirectional camera is used for mapping the environment. By moving the system in the city, a point-cloud is retrieved in real-time. On the other hand, photographs or even videos can be used as a data sources. Using image-based modeling methods, real world objects can be digitized using laser, infrared ray or other mediums (Zhu et al., 2016). This technology is one of the emerging areas in digital reconstruction field, often merged with other techniques such as GIS (Yoo and Han, 2006), procedural modeling (Bekins and Aliaga, 2005; Hou et al., 2016; Müller et al., 2007) and interactive modeling (Musialski et al., 2012). Since raw data is dense and imperfect, approaches for simplification are researched. Both simplification and structure extraction methodologies try to fill the missing parts in the cloud data (Divya Udayan, 2016).

The term 3D modeling, mostly refers to manual mesh modeling applications in practice. Manual 3D modeling approaches are mostly based on polygonal mesh creation (Botsch et al., 2007). Using elements of geometry such as vertices, edges and faces, 3D objects are constructed one by one according to the information provided by user. Users are mostly forced to create objects in a fixed way and construct a hierarchy of simple objects to build a complex model. Even for manual modeling techniques, various workflows are described in order to obtain a 3D object. Thus there are various software which offers various tools that serves to their specific workflow. There are plenty of modeling software out in the market. To name several most popular ones; Autodesk 3D Studio Max, Autodesk Revit, Trimble SketchUp, Autodesk Maya, Maxon Cinema 4D, Aladdin4D, LightWave 3D, Rhinoceros 3D, Blender and more. Most of these tools are designed as suites that integrate modeling, animation, rendering and many additional capabilities within.

In terms of modeling, starting from primitives, objects are created and manipulated in scene. Using control tools, objects can be deformed and subdivided for creating more complex objects. Most of previously-mentioned manual modeling software usually allow custom scripts and plugins that enhance the modeling process. By additions, manual modeling systems can be optimized as parametric environments in a degree. For example, Zweig (2011) had efforts to implement a shape grammar language as a plug-in for Autodesk Maya™ in order to turn this robust manual modeling software into a procedural modeling environment. Additionally, parametric modeling techniques are also used in reconstruction cases. They step up as an effective solution since their interactive nature enables quick creation of large and complex models.

2.2.2.3 Modeling a new design

Other group of applications are aimed for simulation of a future situation. Models are used to visualize and analyze urban features, at their design stage. Every modeling system provides a relatively unique workflow for users. Depending on the desired output, users can select among various modeling techniques. Previously-mentioned mesh creation tools are useful for also modeling new objects. Creating a new model from scratch requires advanced operational tools within software.

Standardized mesh creation tools such as 3dsMax or SketchUp are the most used software in architectural or urban design project visualization. Although they offer specific automated tools for speeding up the modeling process, they are considered as manual modeling tools. They and other manual modeling tools offer a start-to-finish product creation pipeline which one can produce detailed 3D renderings by starting from scratch. However, in order to create a space-specific model, these suites require raw data which is mostly in CAD format. One can create detailed 3D models by using imported data as a reference framework. Manual modeling applications offer solid modeling tools including partly parametric operations that allow users to create amorph geometric forms. However, these applications are mostly based on manual workload to add detail to the design. Another concern, in particular to city modeling, is the ability of the software for integration with GIS databases. Most of the mentioned software does not allow GIS data integration. One of the concerns is that whether or not the software provides accurate models with accurate metric information.

Procedural modeling (PM) applications offer a solution for GIS integration problem as well as many other problems in modeling. Instead of labor-intensive manual modeling techniques, PM automates the modeling process with minimum manual interference. Since it works with rules which include functions, parameters and attributes, the content is defined by the algorithmic operations. These procedural operations can include stochastic rules which give the ability to conform shape into different situations. Hence, a significant number of variations can be generated from a single shape input. Such experiment would become extensive budget consuming if utilized by manual 3D tools such as 3DS Max or SketchUp.

PM is considered as relatively difficult technique. It is an exploratory design tool that is criticized by being difficult to control and accessible only to experts (Gen Nishida et al., 2016). Predefined operations in the PM language such as extrude, split, comp, rotate, translate are limited to a small number. This language requires combining these fundamental operations in rules. Hence, this process mostly does not allow selection and modification of objects by hand. Numerous pros and cons can be counted for PM. Yet, detailed review will be conducted in further sections.

2.2.2.4 Differences in outputs/use application

It is useful here to elaborate briefly on the creation of a 3D model and the distinction between use of the model and use of static images created from it. Depending on the software used, a geometric 3D model of the proposal is created with employing one of the numerous modeling packages. At this stage the modeler has to decide what to represent and how to represent. According to the needs of the project, a representation technique is chosen amongst various media interfaces. However, this process is essentially objective because the information cannot be validated from drawings, the context it is representing or by querying the model directly for heights or widths, etc.

Choosing viewpoints for demonstration is a subjective part. In some cases, the geometric model is transferred to another software program to enhance the rendering by using a photograph of the site for background. When this is done, the accuracy emphasis switches from geometrically accurate to visually correct. That is, acceptable to the eye but not precisely accurate. The image created from the model is static; one is unable to interrogate it for information other than the viewpoint. By controlling the views of the proposal shown, one can manipulate those images to show either the best or the worst aspects of the proposal.

Yet, direct use of the model for representation disallows this. The interactivity allows users to choose any view to experience the model. It allows participants to examine the best and worst characteristics of a development, thereby giving a more objective view of the proposals. The use of the model also allows participants to interrogate its geometric information, thus making the presentation transparent to opaque. From this discussion it can be postulated that the model has a greater potential for objectivity than the image but both require to be validated by other information.

Various researchers debated about the objectivity of 3D models as a central issue. Early discussions mainly based on the viewpoints. Some researchers stated that representations generated from models, as they are geometric shapes in a computer software and there are various viewpoints available. In the other hand some researchers argue that the viewpoints are the main reason that a model could be considered as subjective. Since the representation of early 3D models are static images, the modeler or the artist may manipulate the viewpoints according to his/her intentions. Traditional representation techniques that use only static images force the viewers to observe only outputs of the modelling software or the manipulated versions of it. The perspectives of images or the point of the camera can easily misdirect observer. Since the one that handle the model have the ability to interpret the viewpoints or outputs subjectively, neutrality is the key concern in terms of model development. Early researches showed that confidence and credibility of using visualization modelling would be increased if the direct interaction of the user increase (Pietsch, 2000).

2.2.2.5 Summary of types of modeling

Different methods of modeling have same steps no matter the methods change. Idea of data collection, modeling process and presentation is still applicable as generic process of whole executions. New technologies pave the way for automatic data acquisition techniques. Today's global world is information rich; data creation is much easier in current technology than past analogous techniques. It is not hard to predict it will be much easier in the future. New approaches increasingly expedite modeling processes, and presentation techniques enhance the experience of 3D models by new interfaces. All this on hand, 3D contents are getting easier and faster to be produced.

2.3 Procedural Modelling

Procedural modeling (PM) is a collection of methods that 3D geometries, textures, animations or other materials are constructed using procedures instead of labor-intensive manual modeling. With minimum manual interference, it is used to automate the creation of various output components from a simple set of rules, parameters and shape inputs. PM offers algorithmic generation of content while this parametric process ensures that created objects at each step have the ability to obtain information from their predecessors. This information-carrying nature of PM is one of the reasons to be used for urban planning.

2.3.1 History

Procedural content creation is being researched for more than 30 years. This paradigm is initially used for visualization of natural content such as plants and landscapes. Using procedural approaches in urban modeling is relatively new, both in practice and academic research. Procedural modeling has its roots from the production systems such as L-systems, shape grammars and split grammars which allow creation of complex structures from small sets of inputs (Marvie et al. 2005). L-systems are originated by Lindermayer as a basis for geometric plant modeling (Figure 2.7) (Lindenmayer, 1968; Prusinkiewicz and Lindenmayer, 1990). Output objects are actually a description of sequence of rules which created them (Radies, 2013).

Figure 2.7 : Example of algorithmic generation of plant models by using L-systems (Prusinkiewicz and Lindenmayer, 1990).

On the other hand, shape grammars are introduced as a way of describing geometric shapes in artworks (Stiny, 1980; Stiny and Gips, 1972). It is defined as a set of transformation rules processed consecutively (Figure 2.8) to create a language on a simple initial shape (Mandić and Tepavčević, 2015). Shape grammars are initially used for the construction of architectural design (Stiny and Mitchell, 1978). Split grammars similarly use symbols to derive building models by adaptive subdivision operations (Wonka et al., 2003).

Procedural approaches are increasingly being researched and developed as a new field of computer-aided modeling. The concepts of procedures and parameters help much more efficient modeling techniques. PM techniques are used not only in city modeling but also in visualize natural environments such as plants, clouds, terrains and water areas. Procedural techniques on modeling propose a significant reduction on the weight of output models (Marvie et al., 2005).

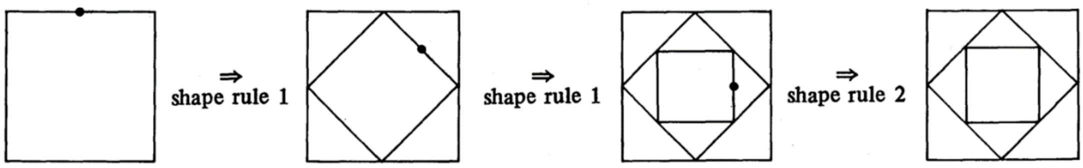


Figure 2.8 : Simple procedure of shape generation using shape grammars (Stiny, 1980).

2.3.2 Main concept of procedural modeling

PM is a combination of various production systems such as shape grammars, graph grammars and L-systems which starts from an initial shape and creates infinite number of output alternatives. Shapes are transformed into models with the help of grammar rules (Figure 2.10). PM employs a bottom-up repetitive creation pipeline which imitates hierarchical system of real world objects such as trees and plants. Main guideline is defined by stochastic rules that iteratively create new shapes one after another, replacing them at each step with the new ones. PM iteratively evolve a design defined by rules and parameters, by adding more and more details at each step of rule execution process.

A single procedural rule can be used to generate many 3D models. For example, the rule can make use of feature attribute information stored in GIS data —such as the number of floors, roof type, wall material type, etc.— to generate a series of alternate 3D models that accurately represent the properties of each feature. If the number of input parameters and attributes increase, possibility to create more detailed and semantic model increases.

It takes relatively long time to learn procedural coding language than a classic 3D modeling software. So learning and costs of procedural modeling is steep at early times. However, nature of the procedural framework of the modeling system exponentially reduces the costs at the long term (Figure 2.9). Because once the necessary coding skills are gained, user can create set of rules for various situations. Rules can be re-used and be supported by additions. When the rules are written in a specific project, manipulation of model is automated with the help of several parameter-modifications.

Figure 2.10 : Main concept of PM on the creation of models.

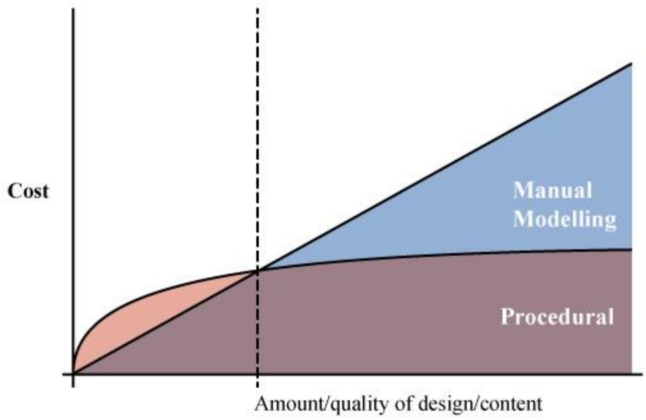


Figure 2.9 : Manual & Procedural modelling cost/amount diagram (ESRI, 2016) (Re-produced by the author).

Thanks to its semantic nature, PM can report back that if certain circumstances are fulfilled in the design process. User can observe the impacts of any change in the design, immediately. For example, an urban designer can track the quantitative change in density of an area while changing the height of a single building within the area. With the necessary variables are connected to each other, internal calculations can trigger each other interactively. Change in total energy consumption of a building can be observed by altering the floor area ratio allowed in the immediate surrounding area. By defining report variables, one can evaluate quality of design in statistical manner. Thus, mass model can be quickly optimized in order to conform the targeted needs. Reporting is one of the most powerful functions of PM, since it enhances the design process by giving automated feedback to the user.

2.3.3 Procedural modeling of cities

Procedural city modeling is initially studied by Parish and Müller (2001) on their pioneering paper. Their revolutionary procedural approach was initially based on L-systems to model cities. Based on 2D input data, their “CityEngine” system generates large-scale city layouts. Thanks to its procedural randomized nature, infinite number of alternative outputs can be generated from a single input.

A generic modeling pipeline in Parish and Müller's (2001) CityEngine can be defined as in steps (Figure 2.11). First, a simple set of image maps; both geographical ones such as water boundaries or obstacle maps, and socio-statistical ones such as density maps or land use patterns can be used as input data. (2) Using extended L-systems, roadmaps are created as graph objects. Roadmaps can also be procedurally generated or imported as it is from external sources. (3) Following creation of roadmaps, the polygon areas between roads are subdivided into polygons according to specified criterion and these allotments are defined as building lots. (4) Next step is building creation which is handled with a parametric stochastic L-system. Every subdivision is allocated with a single building. Types of buildings are pre-defined: skyscrapers, commercial and residential buildings. Each type of building triggers a specific rule to be executed.

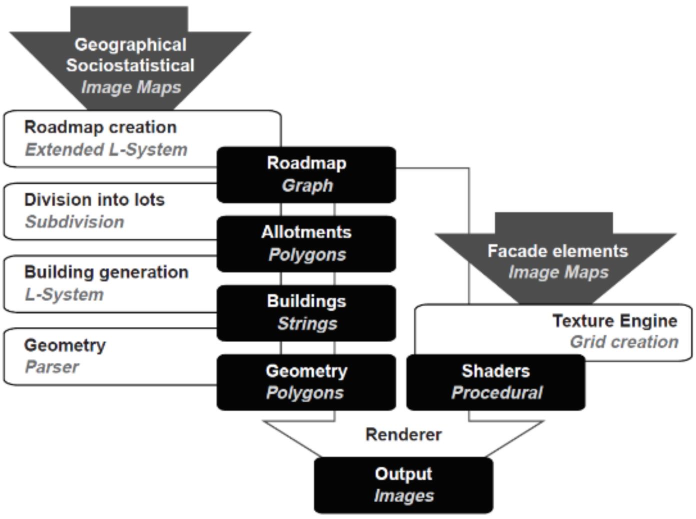


Figure 2.11 : Steps of Parish & Müller’s CityEngine (2001).

At that time, building modeling capabilities of the system was relatively limited. This approach cannot generate necessary geometric consistency since the relationships between different elements are not defined. Yet, an automatic LOD-generation was defined by iterative processes. According to parametric instructions, solid shapes are transformed with boolean operations. As output of the pipeline, polygonal geometry with textures are processed by a parser which translates the string into geometry.

After the pioneering approach of Parish and Müller, many derivative works have been created. One of the important works is conducted by Wonka et al. (2003), extending concept of shape grammars with split grammars to control architectural style. They propose an automated size-independent approach to shape grammars by adding attributes as parameters to shape itself. Rather than creating an individual algorithm for each object, a flexible attribute-matching system is defined for creating variety in the design (Mandić and Tepavčević, 2015). Split grammars include a strict hierarchy from the whole façade to the detailed elements (Figure 2.12).

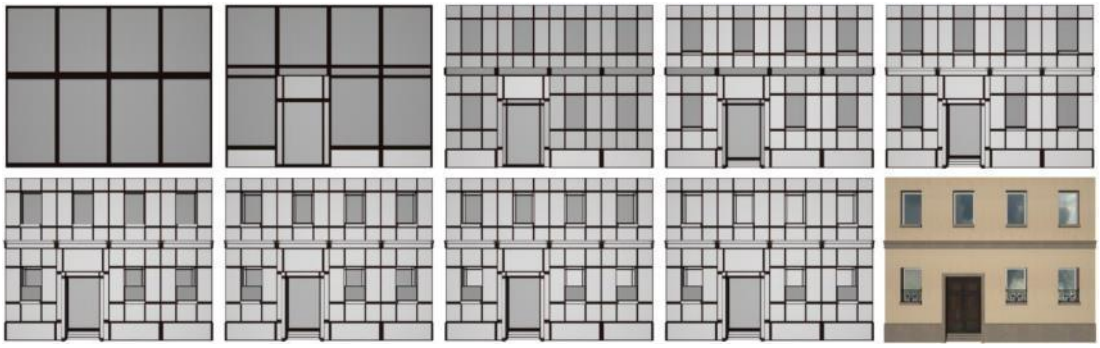


Figure 2.12 : A sample derivation sequence of split grammars (Wonka et al., 2003).

Following, a novel approach is introduced to create entire building facades by Müller et al. (2006). They introduced a new shape grammar language called Computer Generated Architecture (CGA). It is a programming language developed for automatic generation of detailed 3D objects, particularly urban objects such as buildings and roads. It is considered as an extension of shape grammars originally introduced by Stiny and Gips (1972) which aims to define a formal phenomenon to architectural design. It can be considered as a sequential grammar that is similar to Chomsky grammars.

In their approach, production rules create mass models and defines floors, then constructs facades with windows and doors. This hierarchical structure is able to offer infinite number of procedural variations that can be reused in whole city lots to populate buildings (Figure 2.13). Taking a departure from previous work (Parish and Müller, 2001; Wonka et al., 2003), their approach generates detailed building models by using a grammar-based system. CGA has covered some prominent issues such as occlusion queries and snapping. Occlusion provides suitable placement of façade elements according to objects' geometric relationship with other elements. Problem of volumes are not aware of each other, is solved with occlusion queries which avoids intersecting with other volumes (Figure 2.14). Snapping is used for the improvement on the splitting operations for creating better repetitive subdivisions.

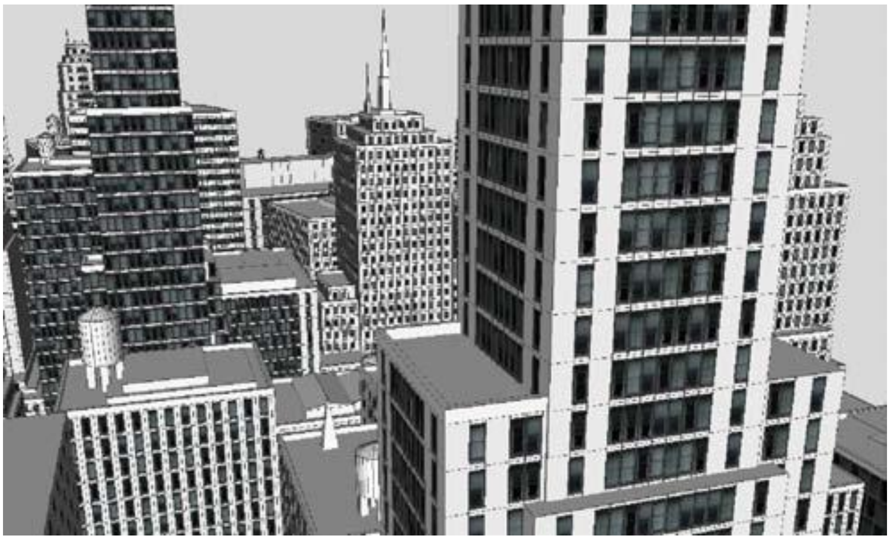


Figure 2.13 : A detailed city model with the help of CGA (Müller et al., 2006).

Figure 2.14 : Occlusion queries and snapping have improved capability of split grammars (Müller et al., 2006).

Paper covers the issues of transition from mass modeling to complex models with façade and roofs. They used concept of shape grammars to create large and detailed urban models, with labor-efficiency. Two researches introduced automatic rule derivation to shape grammars which enables complex city models in the first place. In comparison to L-systems, CGA uses a similar system of rule notation and concept of scope. Yet, CGA operates with the idea of shape replacement which is more suitable for architectural modeling rather than string replacement.

2.3.4 CityEngine

P. Müller and P. Wonka started to develop this system under the software company named Procedural Inc. and released the first commercial version of CityEngine in 2008. Company is recently acquired by ESRI in 2011. From that time on, CityEngine has gained a lot of integration features with the GIS environment, as well as commercial modelling tools such as Maya, Unity and various other software and formats (Figure 2.15). Data interoperability is one of the powerful features of CityEngine since transportation of data is important in the field of modeling.

ESRI CityEngine provides the basis for creation of 3D models procedurally. It uses CGA rules as the main algorithms to create 3D models. CityEngine’s novel procedural

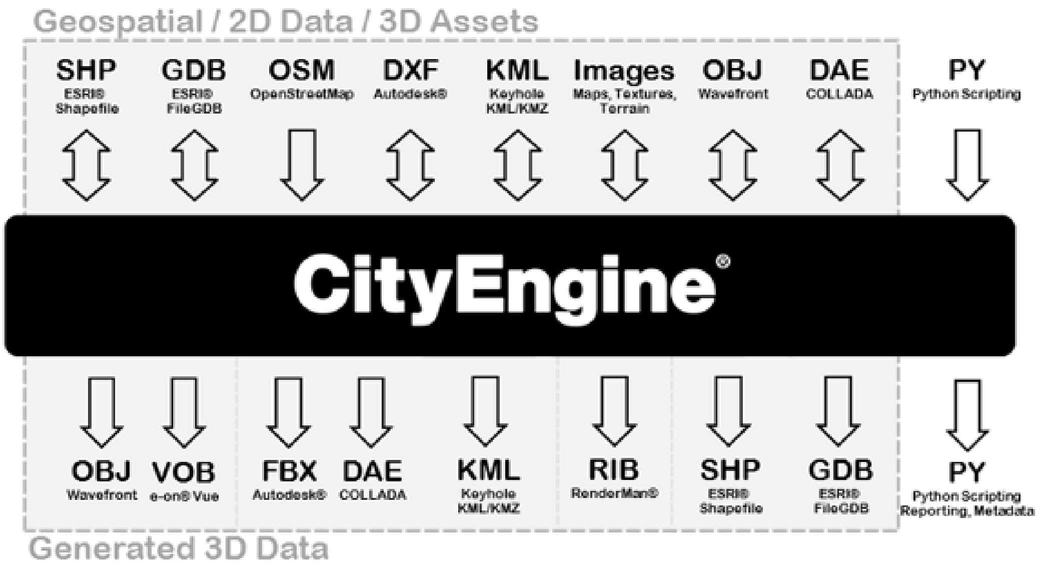


Figure 2.15 : Data interoperability scheme of CityEngine (ESRI, 2016).

system is a modified synthesis of L-systems, shape grammars and split grammars. It has different procedural systems within, which originate from various researches explained previously. (1) Using pre-defined layouts or simple geometric inputs, a city-wide street network can be created according to given criteria and obstacle maps (Figure 2.16). (2) Blocks and lots within a street network can be created procedurally by selecting a subdivision method and defining criteria (Figure 2.17). (3) CGA shape operations create the final models on streets and lots (Figure 2.18).

Figure 2.16 : Example procedural street network.

Figure 2.17 : Block subdivision applied to the street network.

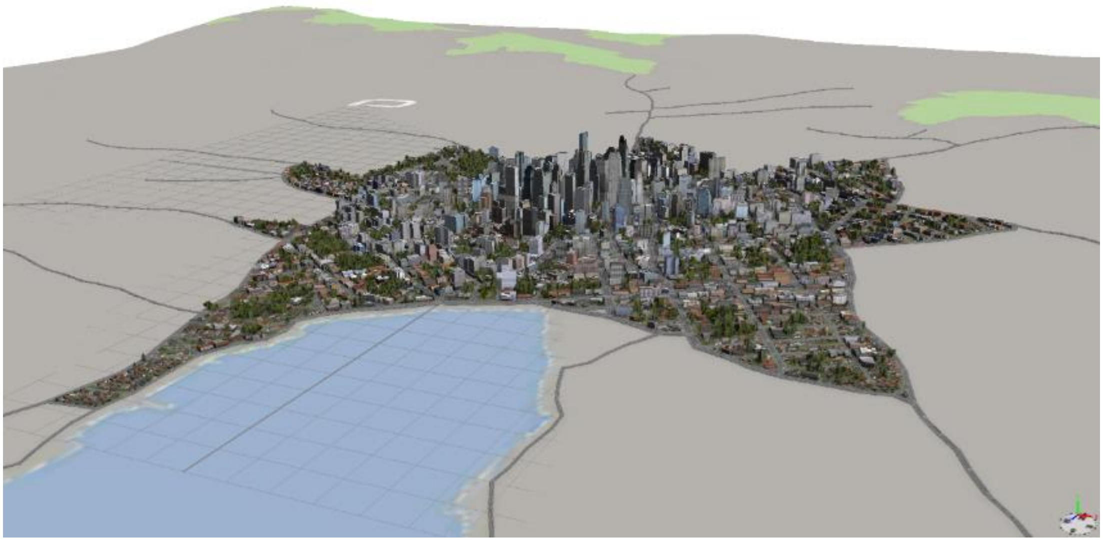


Figure 2.18 : Final result after CGA rules are applied to the procedural city.

A typical interface of CityEngine includes various windows and components (Figure 2.19). Toolbar (1) includes necessary button for the software. Model Hierarchy window (2) is used to observe the grammatical hierarchy of selected shape. Viewport (3) is the main sub-window that 3D scene is displayed. User can navigate and interact with the main content on this window. Inspector window (4) includes the controls for all attributes and parameters of the selected object(s). Console (5) displays printed attributes interactively. CGA rule editor (6) is a text editor to modify rule files. It highlights and checks the written text according to CGA syntax language and shows the errors. Scene Editor (7) organizes the layers, provides the ability to navigate, delete, change visibility or duplicate layers.

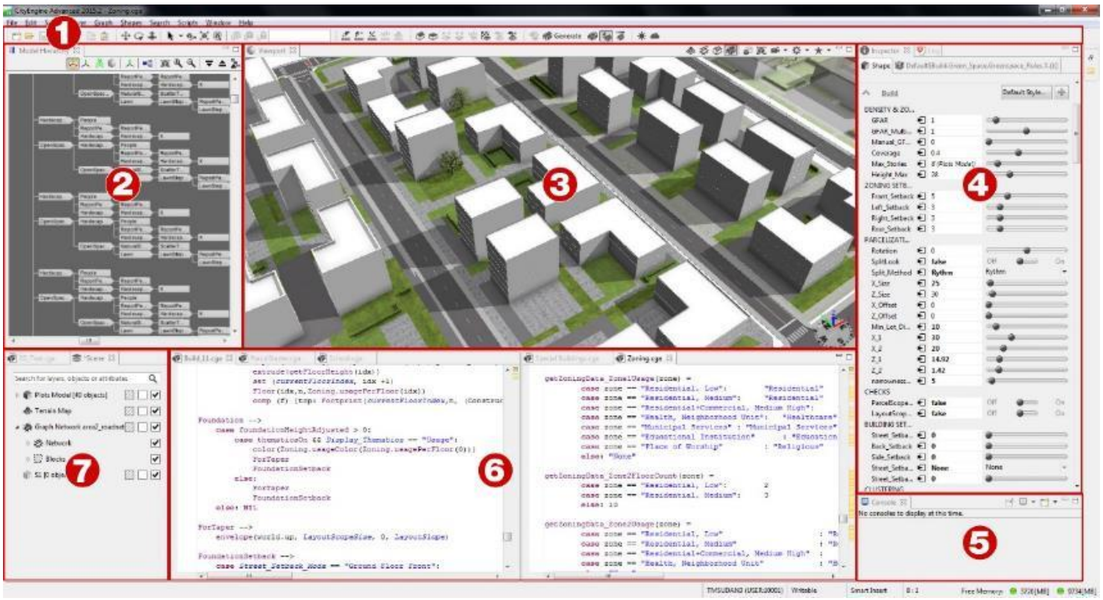


Figure 2.19 : Screenshot of CityEngine interface.

Linking GIS to shape grammars is a significant step for procedural urban modeling. GIS-based geometries can constitute the raw inputs that rules will be applied on. Their shape attributes can be used as rule parameters in CityEngine. This configuration enables direct integration of procedural rules and GIS-databases. Creating a GIS-based planning data in CE, enables a 3D decision support platform (Schaller et al., 2015).

After CityEngine become part of the GIS suite of ESRI, it has been a primary choice for city modeling applications. Features such as batch modeling, importing static models or using GIS datasets transformed CE to a powerful urban modeling and design tool. Entire cities can be modeled at once thanks to CE's batch modeling feature. Importing existing GIS-based data as well as static models in various formats provides a great opportunity to control whole model together in one place.

By defining conditional and stochastic rules, a synthesis of complex and non-linear phenomena can be created (H. Huang et al., 2016). Definition of rule files are not limited; thus infinite number of rules can be executed to achieve results. Same results may be achieved both using only one rule file or multiple rule files.

2.3.5 Recent contributions to procedural urban modeling

Although the mainstream procedural city modeling is developed and commercialized on CityEngine system, there are alternative approaches. Some of these approaches extend the pipeline of CGA rule-based modeling system, while some of them offer a novel system. On the other hand, new approaches to enhance modeling methods are also flourishing. C. A. Vanegas et al. (2010) reports the methods in urban modeling and rendering, visualization and simulation of models.

2.3.5.1 Road networks and city layouts

The hierarchical structure of procedural city modeling is frequently researched in the last decade. Procedural simulations help to grow the city interactively by editing roads or land-use inputs. Studies are made urban simulation engines to define geometrical simulation of city transformation over time. Weber et al. (2009) shows that using city geometry, a simulation system can be established which can simulate a 3D urban environment over time. Similarly, C. A. Vanegas et al. (2009) integrates a behavioral simulator into PM pipeline. This method provides extreme user control and an engine for simulating the city as a whole entity. Additionally, Vanegas et al. (2010) depicts operation and deficiencies of classical shape grammars.

Approaches show that procedural models can be integrated with time component. It is a big step forward to create opportunities to visualize future urban environments and to simulate physical phenomena such as growth, land use or density changes. Probably number of these approaches are likely to increase since new parameters (e.g. natural, economic and geometric) in simulating urban growth. One must keep in mind that precise simulation of urban systems is difficult since they are determined by complex variables such as land policies, market behavior, transportation, infrastructure and population changes (Vanegas et al., 2010). A land use modeler system was presented by Lechner et al. (2006) that uses an agent-based technique to model a city according to procedural land use decisions (Figure 2.21).

Figure 2.21 : Development history of a procedural city based on land-uses (Lechner et al., 2006).

An example-based system that interactively synthesize urban layouts is presented by Aliaga et al. (2008). By using existing street network structure and aerial-view imagery, new urban layouts are created. Various structures of urban form can be blended into each other to create an editable expansion (Figure 2.20). Lipp et al. (2011) proposed an interactive approach on editing urban layout. Their layer-based system offers interactive graph cutting and merging techniques. This approach does not focus on block subdivisions and assumes the subdivision is pre-made.

Figure 2.20 : Blending different types of urban forms (Aliaga et al., 2008).

Creating a road network is one of the first steps in most of the procedural city modeling processes. Plenty of researches are conducted in order to create procedural road networks. By using tensor fields, common network structures are created by G. Chen et al. (2008) (Figure 2.22). A functionalist approach to road generation is presented by Galin et al. (2010) which calculates the costs by considering slope and natural obstacles. Another interactive tool is introduced by G. Nishida et al. (2015) that allows procedural growth of roads based on sketch inputs.

Figure 2.22 : The tensor field is used to create a road network by X. Chen et al. (2008)

2.3.5.2 Land subdivision

Automatic land subdivision methods are used in urban design and planning fields. Lots and parcels are defined by surrounding road networks. Various methods to subdivide blocks to parcels are researched.

Vanegas et al. (2012) have presented a method for procedural generation of parcels. Using the specified attributes, their approach generates spatial subdivision configurations that resembles parcels in real world cities. Interconnected street networks create blocks within, and space-partitioning approach automatically subdivides these blocks.

This study ensured that computerized process can consistently create conformable inner parcels while modeler is editing the outer road network at the same time. Non-direct editing of parcel layout and number ensures different partition styles. User can specify subdivision method as a parameter among one the predefined. Automation of block subdivision has been integrated into CityEngine, as mentioned previously.

2.3.5.3 Interactive editing

The text –based nature is one of the setbacks of CGA grammars in terms of usability. There are studies that outlines the ways of implementation interactive editing of shape grammars. The possibility of interactive local modification of buildings with the help of a real-time visual editor is researched by Lipp et al. (2008).

Barroso et al. (2013) present a complementary approach to PM to shorten the modeling creation time. Their "visual copy & paste" approach provides an intuitive method which enables user to select source objects from any part of a building and paste to a corresponding target area to automatically adopt the modifications as in source building (Figure 2.23). Without any manual intervention it provides ease in modeling process and allows non-technical users to involve in PM.

Talton et al. (2011) presented an example-based algorithm that controls procedural models by geometric shapes to estimate its parameters. On the other hand, graph-based approaches offer a novel viewpoint in interactivity of procedural modeling research (Patow, 2012; Silva et al., 2013, 2015).

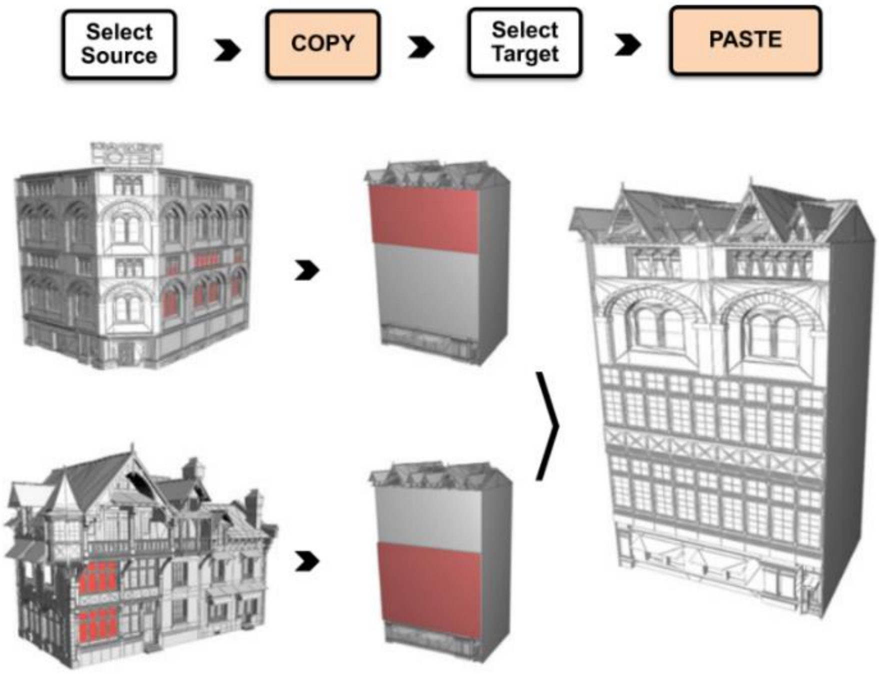


Figure 2.23 : Visual copy & paste system (Barroso et al., 2013).

2.3.5.4 Procedural sketching

Sketch-based modeling systems are another popular alternative. An up-to-date state of art review is made by (Ding and Liu, 2016). They come forward as useful approaches that translates input sketches to 3D objects. For example, Masry et al. (2005) introduced a system for creating a 3D object from sketches in real-time. It can predict axes in 3D world, and help user to draw simple objects with straight edges or planar curves. X. Chen et al. (2008) introduced a seamless system to convert conceptual sketch drawings to realistic architectural renderings (Figure 2.24). From a single viewpoint, user can edit the imagery with consequent sketches. Both complex geometries and textures can be created with sketch inputs.

Figure 2.24 : A 2.5D model is created while sketching in real-time (X. Chen et al., 2008).

Recently, more complex sketch-based systems are developed which integrate procedural approaches. Nishida et al. (2016) proposed an interactive sketching tool that automatically generates procedural models and parameters from the sketched shape. Using machine learning approach, their system is capable of recognizing the best procedural object at a time. In consecutive steps, final model is constructed in parts (Figure 2.25).

Recent work of H. Huang et al. (2016) also shows that new algorithms can be developed an end-to-end system that allow users to create procedural 3D models through freehand sketches (Figure 2.26). Results show that by merging sketch-based modeling with procedural modeling, very complex 3D objects are derived through sketches rather than using parameters. Sketch-based systems are considered as a novel way to control design by non-experts.

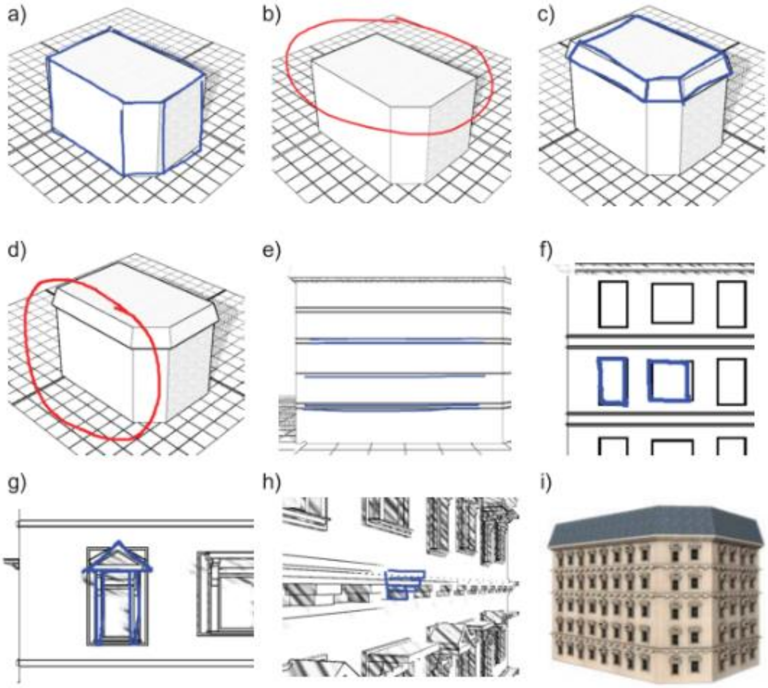


Figure 2.25 : Modeling a building with interactive sketch-based method (Gen Nishida et al., 2016).

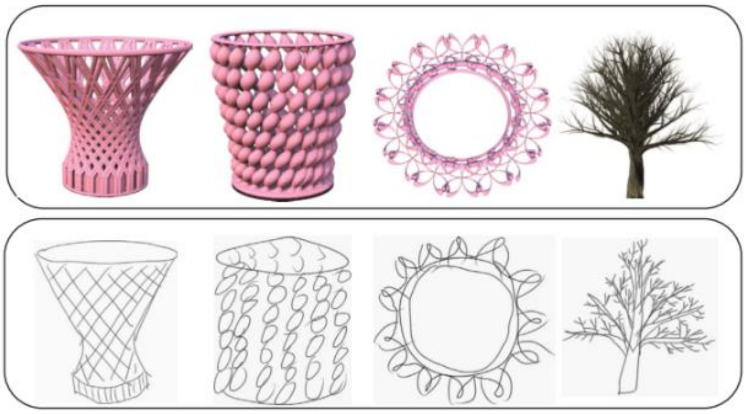


Figure 2.26 : Freehand drawings can be automatically transformed into 3D objects (H. Huang et al., 2016).

Split-based grammars have strict limitations in terms of geometry generation. Recently Schwarz and Müller (2015) showed that CGA grammar language is way open to further developments. Their novel grammar language called CGA++, overcomes limitations of existing approaches.

New methods try to exceed regular grid structure of split grammars, recently. (Jesus et al., 2016) offered a layered system to shape grammars which has the potential to extend CGA by enabling complex layouts beyond its formal structure. With similar concerns, (Zmugg et al., 2014) present a method that allow curved shapes without disrupting procedural pipeline (Figure 2.27).

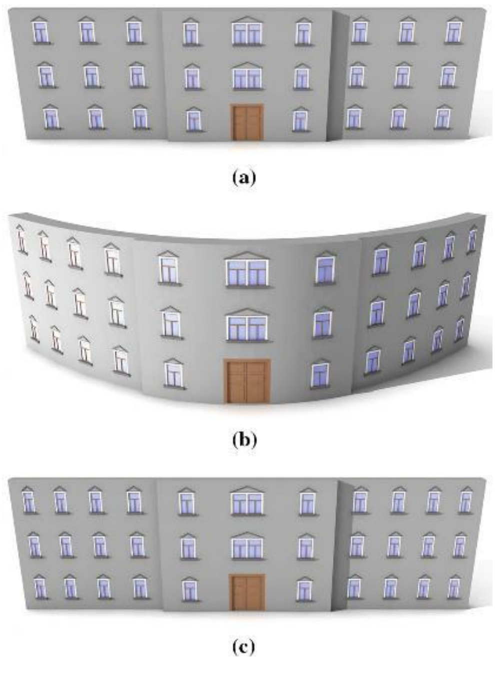


Figure 2.27 : Deformation of split grammars (Zmugg et al., 2014).

Although significant developments are achieved, PM methods are wide open to further developments. There are various setbacks of PM methods such as user control and isolation of techniques. Key requirements of further developments in PM are outlined by Smelik et al. (2014) in their broad survey. Firstly, both local and global manual editing operations are required for PM tools. Secondly, procedural methods need to be unified in a degree since developed tools so far, have only focused on specific features. Thirdly, easier and flexible methods for combination of manual and procedural models are required. Lastly, PM tools need to be more integrated in current 3D content creation workflows.

2.3.6 Use cases of procedural modeling

As mentioned before, procedural modeling methods are used in variety of cases. In this part, use of PM tools as means of design will be outlined. Reviewed cases is not only limited to CityEngine but also various other tools. A state of art review for procedural modeling has been made by Watson et al (2008). Research has reported the usage of PM as a mainstream modeling tool in different fields, nearly a decade ago. Since then, applications of PM have spread out to a wide number of examples. In this section, prominent examples of PM applications will be reported. Although procedural modeling practices cover not only urban design cases, following section includes practices and researches in this field, by a majority.

2.3.6.1 Urban planning and design

Plenty of researches have investigated the applicability of PM workflows in master planning, landscape planning and urban design fields. Conceptual frameworks for high-level procedural city models show that PM can be used by mainstream planning and urban design works (Kunze et al., 2012; Schirmer and Kawagishi, 2011). Figure 2.28 shows a typical example of creating urban design iterations.

Halatsch et al. (2008b) presented an approach that can be used for pre visualization, master planning, guided design variations and general content creation for various industries. Research gave the workflow for master planning using shape grammars and employed some examples that show large urban scenarios can be visualized easily by using this framework.

Figure 2.28 : Volumetric combinations in an urban design project (Schirmer and Kawagishi, 2011).

A recent study is made by Ulmer et al. (2007) presenting a novel approach for grammar-based modeling of urban open spaces. Study shows that different landscaping rules can be created to encode arbitrary interactions between dispersed vegetation around the city. It gives a manageable environment to modeler for automatic generation of vegetation scenarios in the city. An example study is conducted that resembles a typical suburban environment with homogenous layout in the big scale, whereas diverse landscape and architectural details created with stochastic rules (Figure 2.30). Similarly, Neuenschwander et al. (2014) integrated a greenspace typology into procedural modeling environment.

Hayek et al. (2010) have presented green space pattern design approaches for Swiss Village Abu Dhabi Masdar. As a popular case area, Masdar is known as the ecocity of the future. Study presents an approach to employ procedural modeling in a sustainable greenspace planning case (Figure 2.29). Evaluation of alternative greenspace patterns is presented by Halatsch et al. (2010). They showed iteratively developed sustainable urban development scenarios not only in Masdar but also in Zürich. Their system includes evaluation of procedural models in terms of detailed sustainability criteria and created “design guide visualization diagrams” in order to produce performance analysis.

Figure 2.30 : Example procedural models of a suburban environment (Ulmer et al., 2007).

Figure 2.29 : Urban green space areas are modeled with procedural modeling techniques (Hayek et al., 2010).

Conceptual frameworks for urban planning offer solid methods for high-level procedural models. By conducting a survey of building typologies in San Francisco Bay Area, Kunze et al. (2012) have created a framework for using digital design codes to create procedural city models (Figure 2.31). Rua et al. (2013) presented a case study on downtown Lisbon which integrates GIS and BIM features to build a procedural city model which enables spatial analysis and various other usages such as management, tourism, cultural activities and sustainability analyses. Research show that crowd simulation methods are also useful for urban planning cases. By using aspects of procedurally modeled city such as buildings functions and density, crowd behavior can be estimated (Aschwanden et al., 2009).

Figure 2.31 : Collection of created typologies in San Francisco Bay Area case study (Kunze et al., 2012).

There are studies which is similar to this thesis in urban planning and design. One of the similar studies using CityEngine is Albracht's (2016) work. It facilitates several hypothetical design scenarios on UCR District in Manhattan (Figure 2.32). Efforts have been made to combine CE into the planning process as a method of community participation. Study claims that CE may be a good tool for community participation which is mostly considered as costly and time-consuming. Interfaces created within the study might be useful to assist planning adoption processes, create public awareness and attract developers. Later on, the design is intended to be employed in interactive platforms such as Unity game and CE Web Scene. Rules used in the study was mostly based on the example of “Redlands Development” rules which provided by ESRI. However almost no changes were made on example rule files.

Figure 2.32 : Model of a scenario on Albracht's work (2016).

Similarly, CityEngine is employed by Grafton (2016) in dissertation study. Careful observations are conducted on current capabilities of CE. Following several resources such as the zoning bylaws of City of Winnipeg, some manipulations are tested on sample rules. Besides, some additional alterations are made to meet LEED neighborhood design parameters. Capabilities of CE realizing urban landscape systems are questioned.

Choei (2016) employed a case study by generating procedural models of a residential site based on three planning scenarios. According to layout of designs, cost of infrastructure change. Later, by using interoperability tools, outputs of the model is integrated with GIS geodatabases in order to construct the layout of the infrastructure system, to calculate the costs and to evaluate the share of each development on these costs, according to the regulations. Dobraja (2015) have made a similar study on visualization of rural Bavarian buildings in CityEngine in order to test the capabilities of the software to be employed in rural areas. In the case study, building footprints, street network, base map and vegetation elements are imported. As a result; a 3D content is generated as in Figure 2.33. Result has some problems since the footprints, roads and vegetation are separate elements. Some manual work was required to edit elements because they are unaware of from each other. Remaining areas between buildings and roads are not modeled and represented with base map which is fuzzy to represent a 3D reality. However, study shows the capabilities of CE to integrate data from various sources and execute the modeling in very short times.

Figure 2.33 : Generated 3D content of Dobraja (2015).

Duan (2014) presented a methodology to create a CGA code-based template that is suitable to Form-based Codes (FBC) which is an alternative regulation system fostering public realm by opposing segregation of land use (FBC Institute, n.d.). As result, a partial city model is created by applying FBC regulations (Figure 2.34).

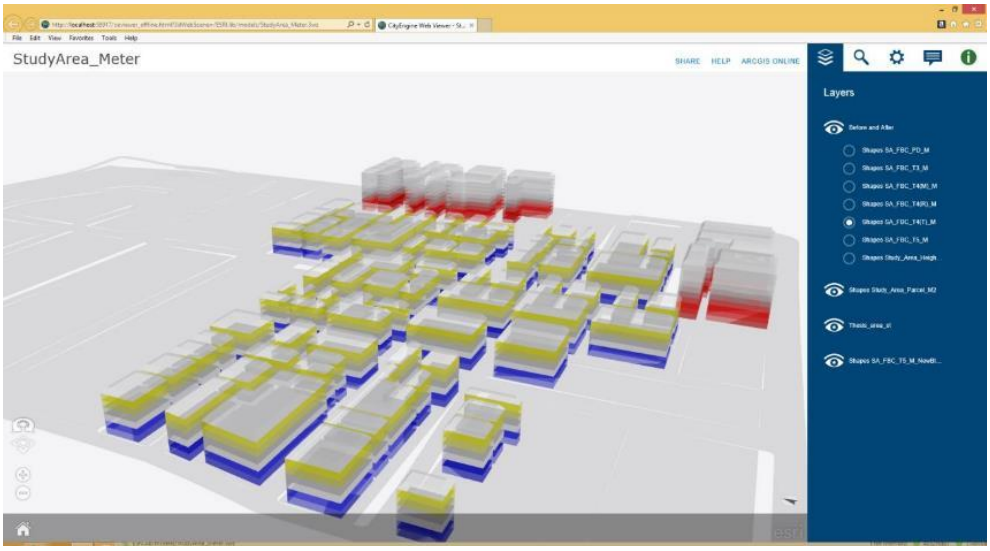


Figure 2.34 : Web scene of Duan's (2014) FBC based procedural model.

Radies (2013) presented a case study in Munich which creates 3D dynamic model of a zoning plan. Legal framework of the plan defined the building borders, and an architectural draft was made on the specific plot (Figure 2.35). Plan is used as information provider for quantitative data.

Figure 2.35 : Zoning plan used on Radies' (2013) case study.

A similar example that use PM as a tool for urban plan creation is conducted by Viinikka (2014). Thesis presents the outcomes of the assessment of CityEngine as a tool to aid planning studies (Figure 2.36). By complying with the Finnish planning system, a masterplan is produced which is suitable for transforming among different iterations and detail levels. Figure 2.37 shows map (1) and model (2) of current situation prepared in ArchiCAD and two iterations (3 and 4) created with CE. CityEngine is proved to decrease number of user interactions (mouse clicks and keystrokes) noticeably, when compared to ArchiCAD.

Figure 2.36 : Viinikka's city model in CE (2014).

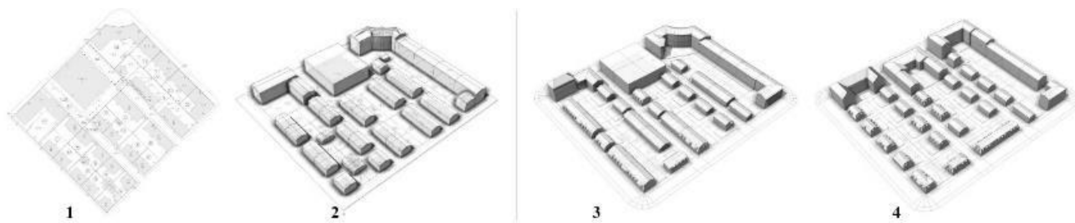


Figure 2.37 : Current situation and planning alternatives created by Viinikka (2014).

2.3.6.2 Archeology and history

PM method was researched in historical reconstruction field by various researchers (Murphy et al., 2013). PM is used in the field of archeology as a tool for analysis, reconstruction and virtual display (Watson, 2008). Since most of archeological sites have a lot of undiscovered areas, PM is used to provide assistance by filling the gap. Using procedural rules, architectural heritage can be re-modeled and preserved in digital way. However, issues such as accuracy and precision emerge in the field of visual prediction of historic sites.

Haegler et al. (2009) argue that PM technology offers an “interesting alternative” to precise and realistic archeological modeling. They present an approach to quickly visualize multiple hypotheses for archeological assets. The study then reconstructs ancient city of Pompeii using the partial floor plans provided by archeological excavations. This work is extended by Maïm et al. (2007); the life in the ancient city is simulated by the behaviors of crowd which is defined by semantic data of the buildings. 3D reconstruction of archeological urban areas can be a generalized process with the help of re-usability of PM rules (Müller et al., 2005).

Similarly, a pioneering project based in the Virtual World Heritage Laboratory at the University of Virginia, aimed to illustrate urban settlement of historical Rome in its most populated times (Frischer et al., 2008). Project was then publicly exhibited in 2007 and model was made available on Google Earth as “Ancient Rome 3D” (Wells et al., 2009). Then, using CGA grammar, rules were created with the help of archeological consultants. City model is expanded with compelling models of buildings whose type and location are not known with great accuracy (Figure 2.38) (Dylla et al., 2008). Another study by Saldana and Johanson (2013) focused on ancient Rome extends previous research by different source of dataset and by complete procedural system that executes rapid-prototyping of iterative models depicting the change of settlement over time.

PM can be conducted as an analysis tool within historical reconstruction field. A recent study presented a method that use GIS-based survey data for 3D reconstruction of possible layout of a classical Greek town (Piccoli, 2016). In a similar study of Konečný et al. (2016), Greek and Roman temples are modeled in detailed architectural scale.

2.3.6.3 Architectural design and analysis

Early study shows that PM is not only for urban design purposes. PM also have been studied at smaller scales than large urban environments such as in the field of architecture, too.

Figure 2.38 : An aerial view from project Rome Reborn 2.2 (Frischer Consulting, n.d.).

One of the early steps on procedural generation of building interiors is conducted by Bradley (2005) which is a practical study creating procedural building interiors given the exterior shapes of buildings. A similar approach by Hahn (2006) is developed to generate building interiors from floor plans according to architectural constraints. The geometry is randomly divided into portions, and some regions are memorized while not-needed-regions are deleted. Respecting the defined constraints, rooms and hallways are created. The system ensures persistency that a specific floor has same plan at each viewing. Martin (2006) developed a method to construct interior structure of buildings. Taking a departure from internal system, building exteriors are also generated. This graphical reflection is supposed to generate more customized architectural units rather than prototypical building styles. Work of Kim and Wilson (2014) also shows that PM can be used for building interiors. This approach also investigated the capabilities of PM to plan and visualize routes within created inner spaces.

Since PM offers fast feedback of the design ideas, it is also employed in architectural decision making process. Zhang et al. (2014) practiced a real estate mass appraisal approach conducting several spatial analysis for improving the efficiency of the real estate valuation. Watanabe (2016) introduced a workflow of procedural creation of traditional Japanese architectural elements. Deshmane (2011) has employed parametric nature of CityEngine to experiment extraordinary architectural geometries.

Rautenbach et al. (2015) presented an approach for modeling and creating a descriptive shape grammar for informal settlements in South Africa.

Other than the research case studies above, example studies can be found in other resources too. A considerable number of case studies are displayed in ESRI's website on urban planning ("CityEngine | Case Studies | Marseille Urban Planning Project", 2016), redevelopment ("CityEngine | Case Studies | Redlands Redevelopment", 2016, "Philadelphia Redevelopment", 2016), real estate ("CityEngine | Case Studies | YouCity Real Estate", 2016) as well as commercials ("CityEngine | Case Studies | Ministry of Sound Commercial by Fold7", 2016, "CityEngine | Case Studies | National Geographic Megacities", 2016, "CityEngine | Case Studies | Prius Commercial", 2016). CityEngine has also been used various productions in film industry. Designers used CityEngine to build 3D cities in movies such as *Cars 2*, *Total Recall*, *Man of Steel* ("Esri Goes Hollywood", 2016) and *Indepence Day: Resurgence* recently ("Build Smart 3D Cities in Minutes with Game-Changing Esri CityEngine 2016", 2016).

These examples are easily augmentable in numbers. Although PM is a relatively new technique for city modeling it is also used for experimenting architectural design. Yet, CGA is one of the most advanced tools available for architectural grammar definition in PM. With the help of a well-designed rule algorithm, very interesting architectural designs can be generated. Stochastic nature of the CGA could help generation of infinite number of alternative designs.

2.3.7 Evaluation of procedural modeling literature review

In this part, procedural modeling as a novel method for modeling urban environment is reviewed. It is considered as a collection of various methods that algorithmically generate content. Although not mentioned in this study, it is also applied for other computer content such as audio and images. It has been a very active research topic in 3D content generation field. In terms of urban planning, PM is used to generate 3d models of huge urban environments.

One of the most advanced commercial software in procedural city modeling is CityEngine. The process of development and the mean of utilization of the software is reported. On the other hand, alternative approaches other than CE, are reviewed in order to grasp parallel improvements in this field. There are significant number of researches in the case of ease of use, user control and interactivity. Additionally, novel simulation systems to grow road networks and city layouts as well as new methodologies for subdivision techniques are reviewed.

Other than development of PM as a computer science, its utilization as a mainstream modeling tool is also reviewed. Case studies in various fields including urban planning and urban design, archeology and architectural design are reported. These cases have proved capabilities of PM as a viable tool for creating semantic city models.

2.4 Evaluation of Literature Review

This section has summed up the researches in three main fields: geographic information systems, three-dimensional urban modeling and procedural modeling. One of the significant outcomes of the reviews is that recent technological advancements offer variety of new techniques. New professional tools are being developed in every reviewed field. A common feature that needs to be mentioned for those tools is; although they are considered professional tools, researches are focused on the interactivity and better user control. Applications that instantly give feedback about the input decision are increasingly being researched. Another significant finding is that applications on those fields are in a hurry to be more socialized. Plenty of case studies show that public involvement on these applications is a common purpose. There are variety of novel techniques especially in the modeling field. As the capability of hardware is developing, plenty of software are emerging. Since the interfaces that general public can access (e.g. common internet browsers) are becoming more advanced, their capabilities for displaying complex content such as 3D models. Therefore, ability to share such content are constantly increasing.

On the other hand, case studies in various fields show that contemporary hardware and software technology is capable of creating immense 3D models which include semantic features. Since visualization is not the only important objective of 3D modeling any longer, novel techniques which combine content and geometry appear to increase in the future. As it is seen in the case studies, semantic 3D models are meant to be an essential instrument of urban planning processes.

3. 3D-GIS BASED PROCEDURAL MODELING IN BEYLIKDUZU

This chapter starts with a short introduction to some definitive aspects of Turkish planning system. Later, brief information about study area for the case study and the planning regulations will be explained. In the following section, characteristics of case study area will be mentioned. After analysis and current situation of the area is depicted, current implementation plan will be examined in particular to case area.

Modelling process in this study has two main steps: preliminary studies and finalization phase. After summarizing current situation and planning regulations in the area, preparation of GIS data to be imported in CityEngine (CE) will be explained. Following the preliminary work for the preparation of GIS data, writing process of Computer Generated Architecture (CGA) rule file will be explained in detail as the first part of the modeling process. This part will report conducted studies before employing the actual CE model. In the second part of the modeling process, written CGA rule file will be applied on selected area. Through the interactive editing of parameters, two alternative designs will be produced. Both alternatives will be associated with current planning regulations. Finally, outputs of modeling process will be deliberated. Both the design aspect and quantitative qualities of design alternatives will be examined.

3.1 Current Planning System in Turkey

In this section, elements and system of planning regulations in Turkey will be mentioned. Both major laws and bylaws those brought into force by central government and plans adopted by local administration will be briefly examined.

Plan-making and implementation processes primarily defined by variety of laws and regulations related with urban planning as basis. Yet, main legislation regulating the spatial development in Turkey is Law No. 3194 on Planning (terms in Turkish as: *3194 sayılı İmar Kanunu*). All of the public and private developments within or out of urban areas are purview of this law. Land use and development is regulated by strategic spatial plans, environmental master plans and local spatial plans. According to this law, there are two types of spatial plans regulating construction. Spatial development plans consist of zoning plans and implementation plans. These plans are made by municipalities in accordance with regional plans or territorial plans if exists.

According to Law No. 3194 on Planning, zoning plans are aimed to depict general land use pattern, types of zones, population densities, the size, principles and direction of developments, transportation systems. Implementation plans are prepared complying with the upper-scaled planning decisions and principles of zoning plans. City blocks are embodied with the layout and density, roads with widths and necessary information about for the implementation of development programs are represented (TBMM, 1985, Clause 5).

The plan used in this thesis is the implementation plan which is the lowest scale plans in the regulation hierarchy. Implementation plans are one of the major instruments of organizing urban environments in Turkey. Plans and plan notes are assumed to constitute a whole. Plan notes depict the instructive regulations in written form that cannot be explained in the plan drawings. "Bylaws on Development of Planned Areas" (BDPA) (term in Turkish as: *Planlı Alanlar Tip İmar Yönetmeliği*) is the regulation that defines a standardized unity in the preparation of building codes and additionally unstated issues in plan notes. This regulation draws a generic framework for planning and building standards to be applied in the entire country (Ministry of Environment and Urbanisation, 2014).

Turkish planning legislation is a multilayered system. There are several plan types defined by the law (Table 3.1). According to planning legislation, every plan must be envisioned and be accordant with upper scale plans. Lower scale plans must be revised by the related institution in one year after the upper scale plans are finalized.

As previously mentioned, planning regulation system is ever-changing. For example, 3194 numbered Planning Law is first published in 1985 and various revisions are made since that date. Total of 24 revisions are made in the law whereas 12 of them is in the last 8 years. "Bylaws on Development of Planned Areas" is came in force in 1985 and revised 16 times since then. 11 of these revisions are conducted since 2008. On the other hand, local plans are updated very frequently. For instance, there have been 37 revisions on the 1/5000 scale zoning plans and 91 revisions on the 1/1000 scale implementation plans in Beylikduzu since 2010. Therefore, such ever-changing legal system is intractable for public and even the professionals to follow.

Table 3.1 : Plan types in Turkey.

Type	Turkish	English
Socio-economic Plans	Kalkınma Planı	Development Plan
	Bölge Planı	Regional Plan
	Stratejik Plan	Spatial Strategic Plan
High-order Spatial Plans	Metropoliten Alan Planı	Metropolitan Plan
	Çevre Düzeni Planı	Territorial Plan
Local Spatial Plans	Nazım İmar Planı	Zoning Plan
	Uygulama İmar Planı	Implementation Plan
Special-purpose Plans	Koruma Amaçlı İmar Planı	Preservation Plan
	Turizm Amaçlı İmar Planı	Tourism –based Plan
	Kentsel Dönüşüm	Land Development Plans
Complementary Plans	İlave İmar Planı	Supplementary Plan
	Revizyon İmar Planı	Revision Plan
	Mevzii İmar Planı	Local Plan

3.2 General Characteristics of Beylikduzu and Its Planning Framework

In this section, general information about the case area, Beylikduzu will be covered. The fact that this area was developed relatively faster than the other districts of Istanbul, its mobility and its parts those are open to urban development are important factors in identifying and defining the borders of the case area. Therefore, the detection of the problems caused by the rapid development of the area designates the potential risks and acts as a guide for not only the said area but also for the areas in which rapid development is expected.

3.2.1 General information about Beylikduzu

Area chosen for this research is Beylikduzu which is a municipal district on the European-side of Istanbul. Beylikduzu is between 41° 01´ 6.80" - 40° 57´ 25.17" north latitudes, 28° 35´ 42.18" - 28° 42´ 1.62" east longitudes. The geographic area of the district is nearly 360 km^2.

The district is one of the newly developing areas in Istanbul Metropolitan Area. District is located in the European side of Istanbul and borders on Marmara Sea in the south, Avcilar district on the east, D-100 motorway on the north and Marmara Sea with Buyukcekmece district on the west (Figure 3.1). It is about 21 km. away from Ataturk Airport and 35 km. from city center. Beylikduzu has a coastline of 12.4 km. On the coastal region, nearly 15 ha. area was occupied by the largest container harbor of Turkey.

District was a rural fisherman's village at the time of Byzantium and Ottoman Empires, occasionally used as military dormitory base. Total population of three villages that consist Beylikduzu today, was 1559 in 1935. A considerable amount of agricultural production was reported in Beylikduzu. Until 1990's, Beylikduzu had been consisting of country-side summer resorts and secondary residential houses. Today, Beylikduzu appears as a planned city with mass housing projects, luxury housing sites, ample green areas and wide boulevards. Especially after the Marmara Earthquake in 1999, Beylikduzu took a lot of attention with new developments. A considerable amount of population migrated to Beylikduzu to vacate poor quality housing areas in Istanbul. Recent developments in transportation systems such as metrobus line triggered the second migration wave into periphery urban areas such as Beylikduzu.

Figure 3.1 : Place of Beylikduzu in Istanbul.

3.2.2 Administrative history of Beylikduzu

Today's Beylikduzu is an area comprises of old Yakuplu, Kavakli and Gurpinar villages, according to the 1924-dated Village Law (terms in Turkish as: *Köy Kanunu*). In 1994, with the municipality law these villages were turned into urban settlements and Beylikduzu became an area composed of three different towns (terms in Turkish as: *belde*). In accordance with the Law no. 5216, dated July 10, 2004 on "Metropolitan Municipality", the borders of municipality were enlarged on the borders of city and thus the scope of authority and responsibility of Istanbul Metropolitan Municipality has tripled in size. With this law, the town municipalities (terms in Turkish as: *Belde Belediyeleri*) were converted into first tier municipalities and attached to the Istanbul Metropolitan Municipality in terms of administration.

Pursuant to the Law no. 5747, dated March 22, 2008 on "Constituting Districts within the borders of the Metropolitan Municipality and Making Changes on Some Laws" (terms in Turkish as: *5747 sayılı Büyükşehir Belediyesi Sınırları İçerisinde İlçe Kurulması Ve Bazı Kanunlarda Değişiklik Yapılması Hakkında Kanun*), eight new district municipalities have formed and the number of districts rose to 39. As a result of this adjustment, Beylikduzu became one of the residential areas that turned into district municipalities.

As is seen from administrative regulations, slight changes on the settlement character of Beylikduzu area caused urgent administrative measures. As a matter of fact, Beylikduzu population dramatically increased in past two decades. This dramatic increase is depicted in Figure 3.2, as total population of three villages (Gurpinar, Kavakli, Yakuplu) was nearly 5,000 where the same area contains a population of 300,000 at the end of 2015.

3.2.3 Beylikduzu Planning History

As stated in the last part, Beylikduzu district was administratively constituted in 2008 by merging three villages of Yakuplu, Kavakli and Gurpinar. When these villages were administrated under a different local governance, local zoning plans have been made and approved between 1989 and 1994. After the three villages turned into township municipalities, zoning plans have been revised on different dates. As of 2004, authority to prepare and approve plans in this area has been transferred to Istanbul Metropolitan Municipality (IMM). Therefore, IMM is responsible for preparing and approving

1/5000 scale zoning plans and approving 1/1000 scale implementation plans, as township municipalities was responsible for making 1/1000 scale implementation plans. In 2008, district of Beylikduzu has been established. As of this date under authority of Beylikduzu Municipality (BM), zoning plans has been revised on regional basis as well as on the parcel basis.

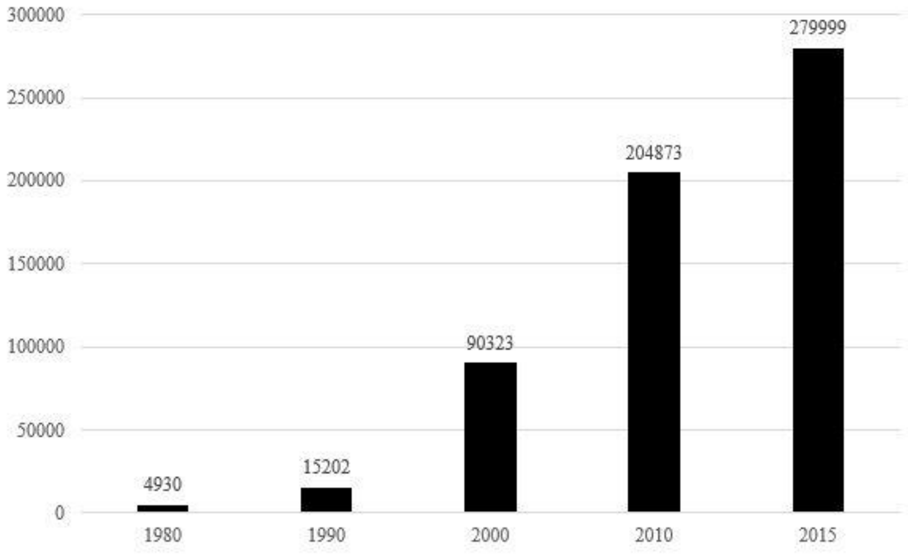


Figure 3.2 : Population change in Beylikduzu. (Source: TUİK)

Due to aforementioned reasons, currently there are 3 different plan areas within Beylikduzu border; Yakuplu, Kavakli and Gurpinar. For Yakuplu area, 1/5000 scale Yakuplu General Revision Masterplan and 1/1000 scale Implementation Zoning Plan were approved on 2004. For Kavakli area, 1/5000 scale Beylikduzu Zoning Masterplan was approved on 2005 and 1/1000 scale Beylikduzu Implementation Zoning Plan was approved on 2007. For Gurpinar area, 1/5000 scale Gurpinar Zoning Masterplan was approved on 2010 and 1/1000 scale Implementation Plans were approved on 2011.

Currently approved plans of the district are relatively developed in the near past (Table 3.2). Presently, there are three different plans in the district which are developed in turn. Long history of planning in the district is related to recent administrative derangements. At present, although currently approved plans are stable for a long time, still a lot of plan revisions held in Beylikduzu due to its vibrant urbanization dynamics.

3.2.4 Examining the planning regulations in Beylikduzu

Following part examines 1/1000 scaled Beylikduzu Implementation Plan in detail and provides a premise for the integration to workflow of this study. Regulation system of the implementation plan has different elements. There are 4 main instructive elements of implementation plans; Floor Area Ration (FAR), Building Coverage (BC), Maximum Height and Number of Floors. FAR is known as *"Emsal"* in Turkish; defines the maximum permitted construction area for the plot. BC defines the maximum area that building footprints can cover on the plot surface. Maximum Height (Hmax) is the maximum permitted height of the construction in meters. Number of Floors is the number of maximum permitted floors on the plot. These elements are the ones that are used to define the total permitted construction rights in generic situations.

Table 3.2 : Dates of recognition of the plans in Beylikduzu.

	1/5000 Zoning Masterplan	1/1000 Implementary Plan	Coverage
Gurpinar	03.10.1995	03.10.1995	Partial
	03.01.1997	03.01.1997	Partial
	19.06.2002	19.06.2002	Partial
	28.10.2003	28.10.2003	Partial
	06.10.2000	06.10.2000	Revision
	08.08.2010	09.06.2011	Full
Kavakli	16.03.1999	-	Revision
	09.08.2002	-	Revision
	26.05.2003	-	Revision
	15.05.2005	21.01.2007	Full
Yakuplu	25.12.1996	25.12.1996	Revision
	16.02.2004	16.02.2004	Full

Implementation plan has some regulative styles on the map that combine one or two elements to define construction limitations of a plot. According to local characteristics, regulation style changes. With the first common type, implementation plan has markings on many plots, as in Figure 3.3. This signage is generic one for most implementation plans. "A" letter on the left designates "Detached buildings" (term in Turkish as: *Ayrık*) and indicates that buildings on that particular plot should be constructed with a minimum distance of side yard length. The number in the middle indicates side yard length. The number on the top shows minimum front yard distance. The number at the bottom indicates back yard distance. With the help of generic provisions on the Plan Notes, this signage defines the limitations for most housing plots. In this regulative type, implementation plan has signage and BC together on some plots, as shown an example on Figure 3.5. With this usage, some of the key limitations on the plot is made. This method ensures the layout style, floor number, setbacks and floor area of the particular plot.

Second type of layout regulation is coupling *FAR* and *Hmax*. In this type, *Hmax* is restricting the height and *FAR* is restricting the total construction area (Figure 3.4). In this type of regulation, floor area and number of floors are not limited to a certain number. So, this gives the developer maximum number of alterations on the layout and form of the development.

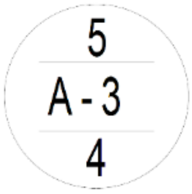


Figure 3.3 : Generic signage for common plan regulations.

On the other hand, there are plots that do not have a specific regulation unlike examples given above. In cases like this, plan notes have various articles regarding the gross construction area (GCA) values. There are regulations that defines spaces within buildings which are not calculated within GCA (Beylikduzu Implementation Plan Notes Article 7, 8,23.3, 24.8, 26). There are also articles that defines free GCA regulation on certain functions. Plan notes indicates that projects of development on specific zoning plots will be approved by Beylikduzu Municipality or Istanbul Greater Metropolitan Municipality (Beylikduzu Implementation Plan Notes Article 14, 15, 16, 23.4, 24.1, 24.4, 24.5, 24.12). Plan also have articles about bonus GCA regulations if plot geometry meets certain conditions (Beylikduzu Implementation Plan 23.2, 23.4, 23.5, 24.11, 24.12, 26). As setbacks are drawn or annotated on plan drawing, articles regulating setbacks and minimum distances between buildings were indicated (Bylaws on Development of Planned Areas, Article 17; Beylikduzu Implementation Plan Notes Articles 25.1, 25.3). In order to create meaningful geometry size for development, plan indicates various values of minimum lot size (Beylikduzu Implementation Plan Notes Articles 12.1, 25.2).

In general terms, 1/1000 scale Beylikduzu Implementation Plans (Figure 3.6) follows the structure of 1/5000 scale Zoning Plans. The density distribution of Beylikduzu plans is depicted in Figure 3.7. As seen from the map, northern areas of the district are more densely planned than southern areas. To depicture the plans for better understanding, number of floors have been analyzed for plan function plots if indicated in the implantation plan (Figure 3.8). Map of maximum allowed number of floors also shows northern and partly southern areas have been planned as low-density with rural characteristics while northern areas and partly eastern areas have been planned as high density neighborhoods with central characteristics.

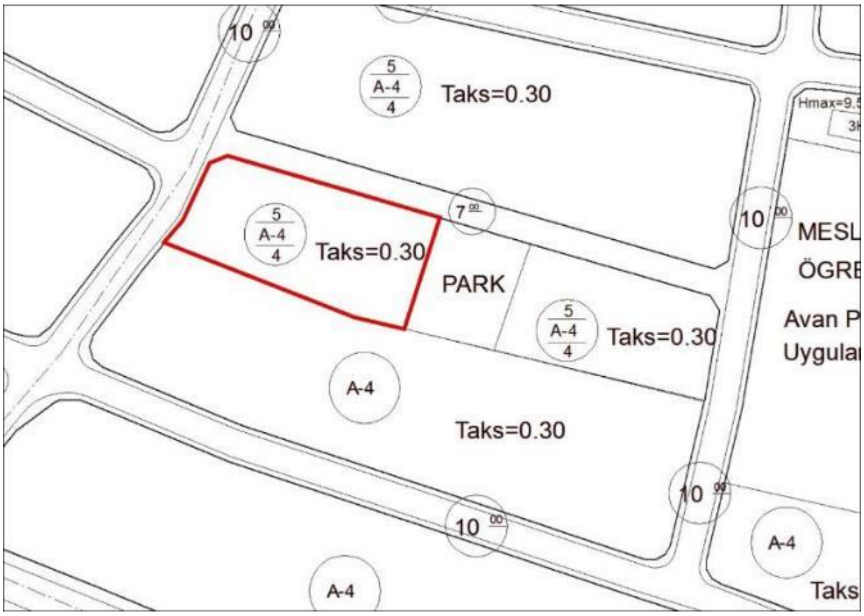


Figure 3.5 : Example of Building Coverage (TAKS) usage with signage.

Figure 3.4 : Example of FAR (E) usage with Hmax.

In this section, general analysis of the implementation plan technique is conducted. Ideas for development of planning techniques and conflicts will be given in the conclusion section coupled with the integration of CE.

Figure 3.6 : Implementation plan of Beylikduzu in CAD format.

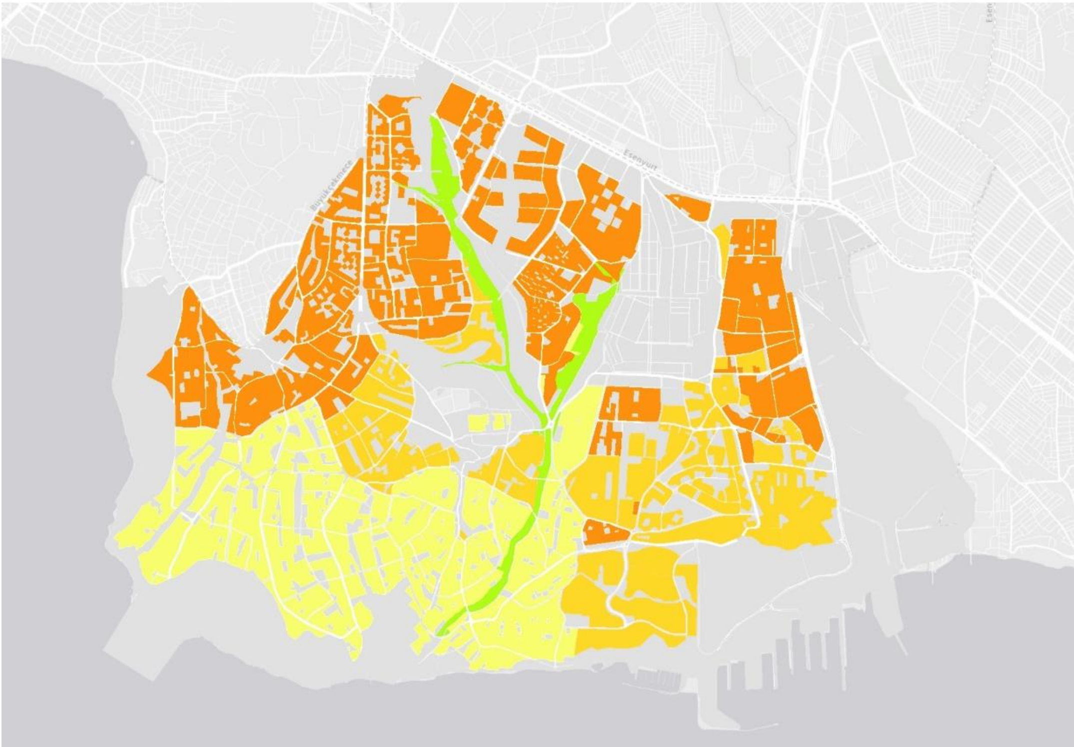


Figure 3.7 : Map of density regulations indicated in zoning plan.

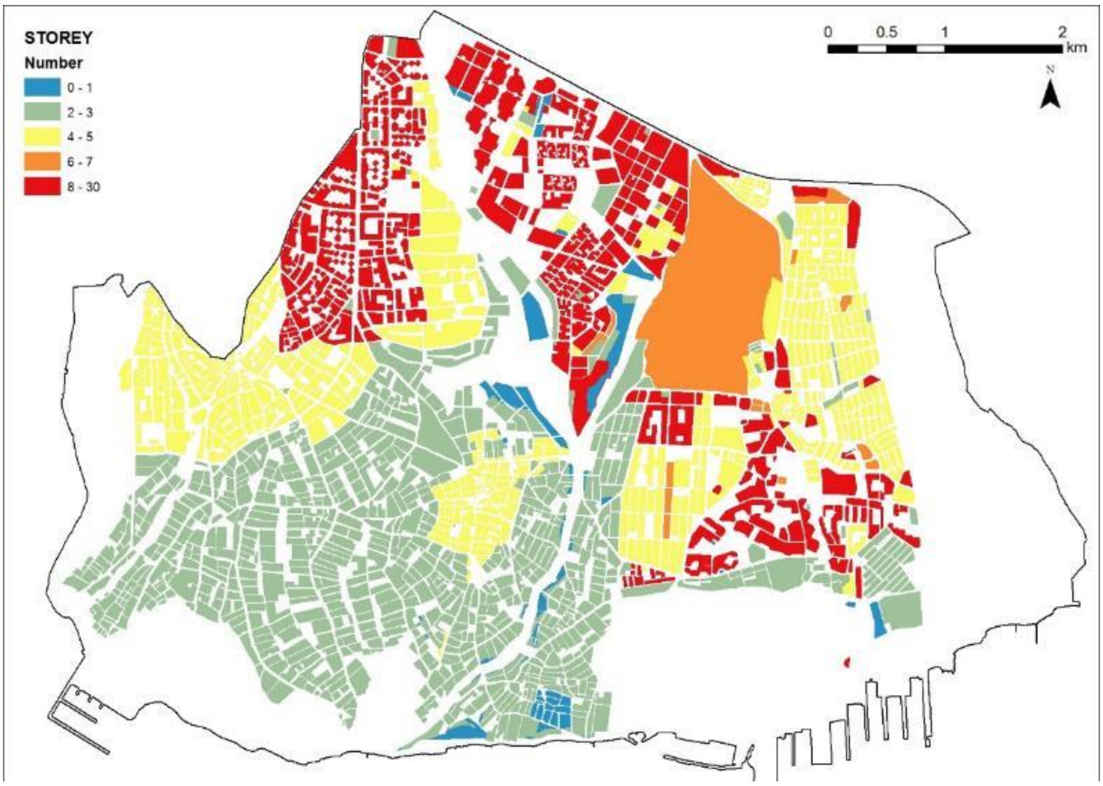


Figure 3.8 : Map of the maximum number of floors for function plots indicated in implementation plan.

3.3 General Characteristics of the Case Area and Planning Decisions

As mentioned before, Beylikduzu district is a newly developing area and nearly half of the land is not developed yet (Figure 3.9). Undoubtedly, procedural modelling is a practical tool to conduct an urban design for undeveloped areas. Thus, modelling such a big urban area requires almost same human workload as modelling smaller areas. However, detailed analyses are aimed to be conducted on outputs of the modeling process in particular to this study. It would be easier to compare and analyze the outputs of the alternative designs of a narrower area.

Figure 3.9 : A preliminary procedural city model of Beylikduzu depicting present-day developments.

Additionally, due to fact that outputs of modeling process are aimed to be shared online, extent and size of the shared models are critical concerns. Preliminary studies and examined case studies show that sharing weighty models online is a fact that reduces interests of viewers.

For the case study, a limited case area is chosen within Beylikduzu border as depicted in Figure 3.10. As previously mentioned, center of Beylikduzu is considered as its northern part where main transportation routes are tangent to. Northern part is nearly developed with full capacity. From north to south, percentage of developed areas gradually decrease. The most undeveloped areas are south – southwest areas of Beylikduzu.

Chosen case area is relatively undeveloped compared to center of the city. Additionally, planning layout of the area is suitable for the interpretation of PM application of this study. Size of the case study area is 31.2 ha. Case area contains 212 parcels which have an area of 237,144 m^2. Size of the parcels vary from minimum 547 m^2 to maximum of 12,680 m^2. Mean size of the parcels is 1,118 m^2 where standard deviation is 1,559 m^2.

Figure 3.10 : Study area in Beylikduzu.

In compliance with this data, the parcels in the case area may be considered as suitable for the construction of both single buildings and mass housing blocks, allowing to plan gated communities. Although the current development does not constitute the adequate sample for certain determination, characteristics of present buildings support the foresight of gated communities. Only 9 out of 212 parcels have developed and there are 15 buildings entirely constructed in these parcels.

Latest official actual maps and satellite images are dated to 2013. Hence, satellite image on Figure 3.11 and base map in Figure 3.12 depict the site as less constructed than the actual situation. However, actual situation is slightly different than 2013. As seen from the Figure 3.14, this area is filled up with new development constructions. Yet, analysis of current situation will be conducted with available GIS data.

Figure 3.11 : Satellite imagery of study area.

Figure 3.12 : Map of current situation of case study area.

Figure 3.14 : Street view from the study area.

As mentioned previously, case area is approximately 31 ha. A quick view on planning regulations of the area show that this area is planned as housing neighborhood in medium density (300 p/ha). According to 1/5000 scale Zoning Plan (Figure 3.13), 22,9 ha. of the area is planned as new development housing area. Remaining areas are planned as Green Spaces, Commercial + Residential Use, and Educational Institutions (Table 3.4).

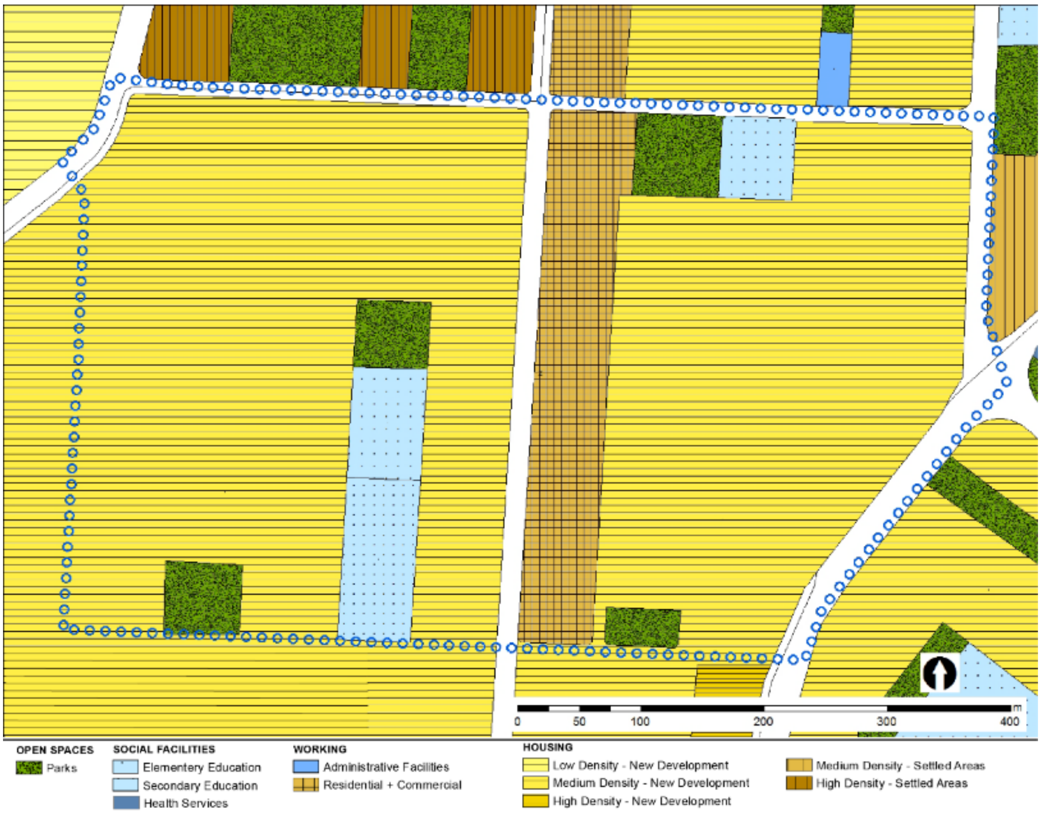


Figure 3.13 : 1/5000 Zoning Plan in the case area.

Similarly, according to 1/1000 scale Implementation Plan (Figure 3.15, Figure 3.16), most of the residential land uses have a FAR value of 1,6 with the maximum height of 15.50 m. Green Spaces are mostly used as parks and parking area (BIPN, Clause 18) in one parcel. Educational institutions are used as both preliminary schools and secondary education schools which are subject to BIPN, Clause 16. In addition, two linear parcels are defined as mixed-use areas which are defined in BIPN, Clause 24 (Table 3.3).

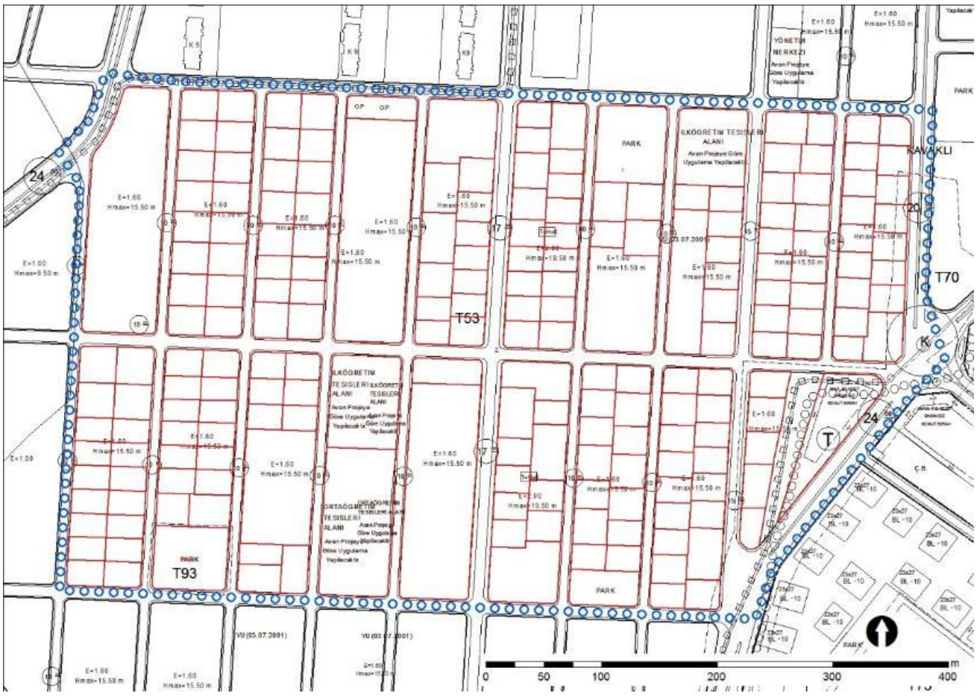


Figure 3.15 : Borders of the study area on the implementation plan.

Figure 3.16 : Implementation plan symbolized in GIS.

Table 3.4 : Areas of planned land uses in the case study area.

Land Use	Area (ha)
Residential	22,9
Commercial + Residential	2,6
Educational Institutions	1,7
Green Space	1,3

Table 3.3 : Areas and FAR values in the implementation plan.

Land Use	Area (ha)	FAR
Residential	17,2	1,6
Commercial + Services + Residential	2,5	2
Preliminary Education	0,9	Plan Notes, C16
Secondary Education	0,7	Plan Notes, C16
Green Space	0,9	-
Parking	0,1	-

3.4 Preliminary Studies for 3D-GIS based Procedural Modeling

In this part, preparatory work before actual modeling process will be described. After the preliminary studies and modeling part is finished, two alternative design scenarios will have been built as in Figure 3.17. Designs will be geometrically distinctive, since one of the objectives of the modeling process is to show that plan regulations give enough margin for the designer to place a building in various ways. Additionally, alternative layouts are examples for demonstrating that both plan and ownership pattern in this area can offer various design scenarios. Although only two alternative layouts will have been built in this study, there would be infinite number of alternative layouts in this area according to individual parcel layouts. Therefore, these alternative design scenarios will show that the practical disconnections between planning, urban design and architecture can be supported by the frameworks such as the one studied in this thesis. In order to describe a methodological workflow for transforming a plan drawing in Figure 3.15 into urban design layouts as in Figure 3.17, a modeling pipeline is designed which will include regulative tools in the planning legislation by defining them as procedural parameters.

Figure 3.17 : Layout plan of two alternative outputs.

Main pipeline of the entire modeling process is summarized in Figure 3.18. According to this workflow; first part of preliminary studies include preparation, modification and exporting of necessary files from GIS environment to CE modeling pipeline. In the second part of preliminary studies, creation of a new ruleset in CE will be reported. Main elements and operation principles of the rule file will be explained by testing it on shapes and reviewing. Subsidiary rules such as road creation and greenspace construction are outsourced from example case studies provided by ESRI. Rule utilization work in this study covers the definition of algorithms that take parcels to create 3D buildings.

3.4.1 Digitization of the implementation plan on GIS

The dataset used in this workflow is mostly prepared and modified in ArcGIS software. Most of the data acquired from Beylikduzu Municipality. Main component of the dataset is digital version of 1/1000 scaled Beylikduzu Implementation Plan. Municipality has the plans in another CAD format. Plan was formerly prepared in NCZ format, which is similar to DWG file. Coordinate system of the drawing is UTM3, datum is ED50. NCZ is the native format of NETCAD software which is developed by a Turkish software company. It is mostly used by public sector and private companies related to planning and geography. NETCAD GIS, is a software package that includes both CAD and GIS features ("NETCAD GIS - ENGLISH - Netcad Help", 2016). It supports international standards and formats, although it is used as a close system by Turkish users with its native CAD formats.

To be able to use the plan, implementation plan is transformed into DWG format which can be recognized by ArcGIS. Data is imported to ArcGIS and transformed into shapefiles as it is the native format for both ArcGIS and CityEngine. At the end of this process, the data has been ready for the establishment of attribute data on shape files.

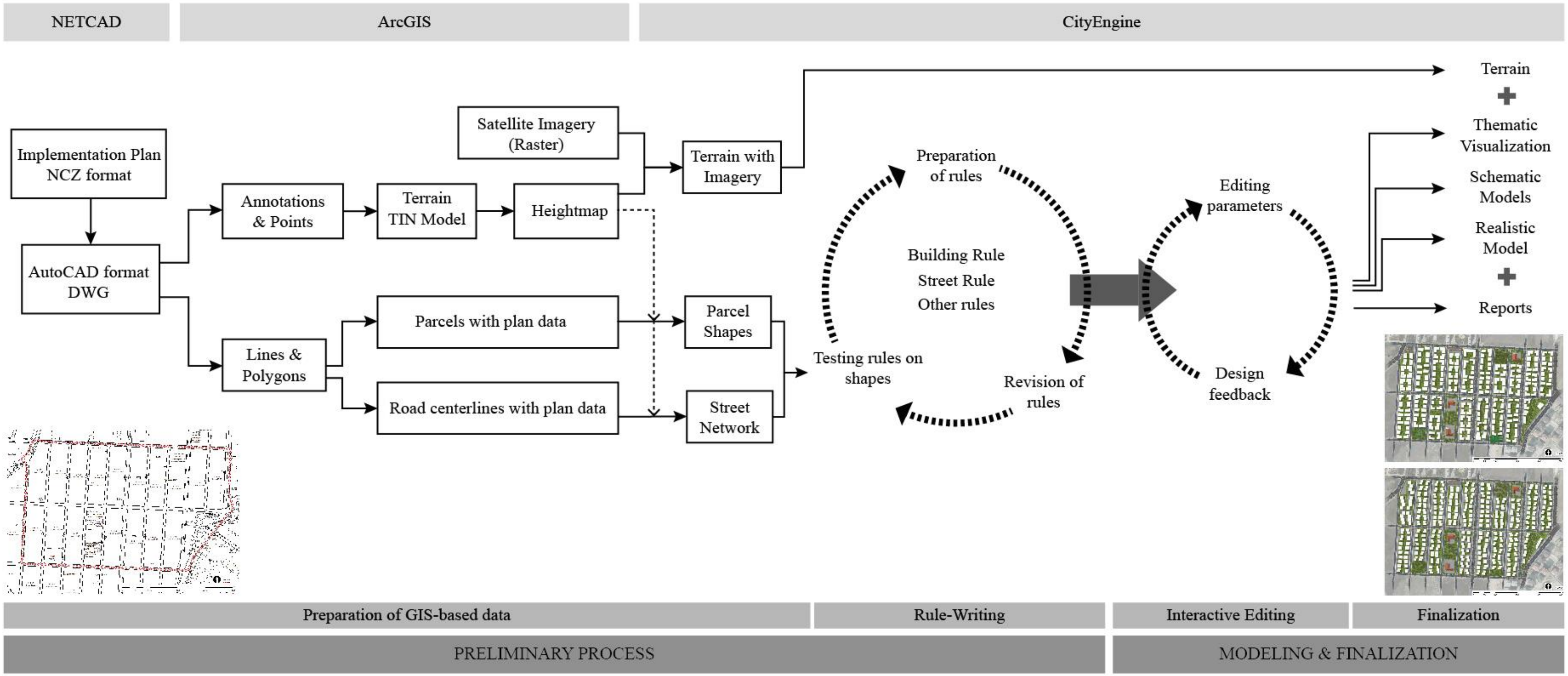


Figure 3.18 : Main pipeline of modeling process.

There are various means of imprinting attribute data into a shapefile in ArcGIS. The simplest way is to handle the entry manually, which requires lot of workload if the dataset is big (Figure 3.19). However, ArcGIS has a lot of powerful tools that one can relate and cumulate data from several other feature classes by means of geographical reference, feature similarities or any other criteria that user can formulate.

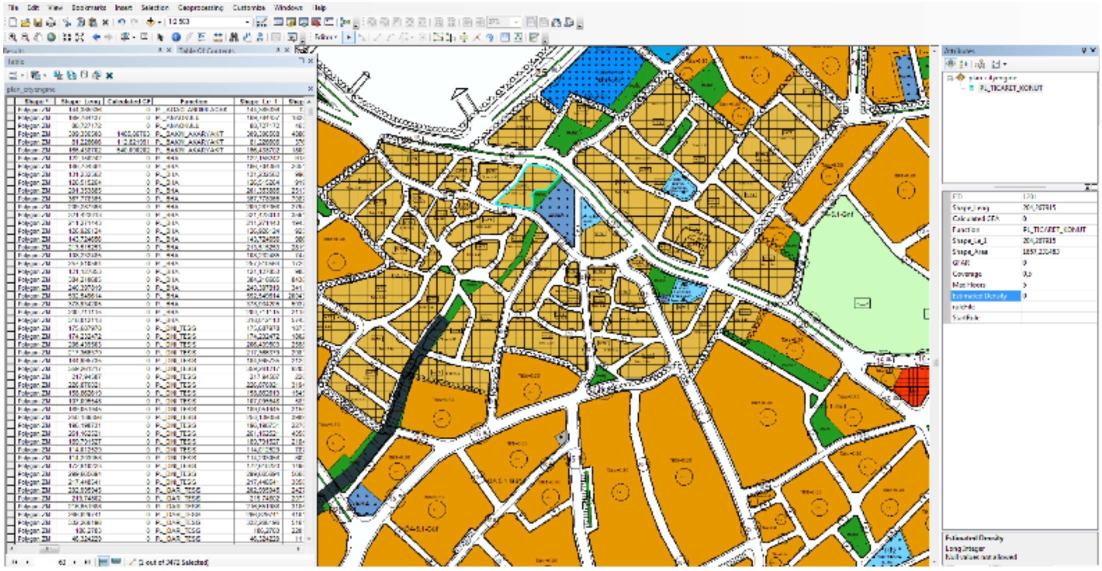


Figure 3.19 : Data processing into shapes in ArcGIS

Once present attributes are merged into shapes, new attribute fields are created in order to process information to be used in CE. As stated previously, the workflow between two software allows CE to read specific attributes within shapefiles. When the shapefile is imported to CE, procedures to read shapefile attributes are defined by simple codes. Shape attributes can be pre-defined in ArcGIS before importing into CE. For example, *"ruleFile"* field is imported since it defines the path of the CGA Rule File that CityEngine will use automatically when imported into software. This workflow expedites the process when it comes to big data, since it is easier to parse and select specific shapes in ArcGIS.

From the plan database, three different types of GIS-based data are prepared. First, annotations on the plan are used by merging them into the parcel shapes in terms of geographical relation. Annotations on the plan are separated into layers such as maximum number of floors allowed, BC, FAR or allowed layout type. These attributes are imported into parcels so that all parcels have the necessary information for building. Secondly, road centerlines are created in ArcGIS and then street width attributes for each segment is embedded into polyline shapefile. Features that cannot be related with present numeric information automatically, processed manually. Thirdly, another important component of the urban model is actual terrain and satellite image of the city. One of the most used topographic elements is TIN (Triangulated Irregular Network) which includes topological relationships between points and neighboring triangles ("TIN dataset | Definition - Esri Support GIS Dictionary", 2016). Present base maps of the area have topographic information in point data. This point cloud is used to create TIN dataset which is the most accurate model of the real topography. In order to overlap satellite image into topographic model (TIN), a TIFF raster image is exported with the same extent with TIN model.

3.4.2 Creation of dataset on CityEngine

Actually, three basic files are what CE needs to build an urban model used in this work. Needless to say, various datasets may be prepared to be used in a detailed modelling process. Information related to present situation of the city such as location of trees (with their specific characteristics), all kinds of urban furniture (lamps, antennas, garbage cans etc.) or extraordinary urban elements can be mapped and modelled in CityEngine – both procedurally and manually. However, for this work to be as simple as much, urban elements are limited to parcels, roads, buildings and open spaces. Consequently, for creation of 3D models, several data types were collected and imported into CE (Table 3.5). Although procedural modeling requires simple data inputs to create extremely detailed models, preparation of GIS-based data is a crucial process for place-specific modeling process.

Table 3.5 : Information of the dataset that imported into CE.

Data	Format	Data Size	Source	Contents
Parcels	SHP	34 kb	Implementation plan polygons + Annotations	212 polygons
Street Network	SHP	10 kb	Manual tracing	78 line segments, 60 nodes
Imagery base map	TIFF	5186 kb	Beylikduzu Municipality	Imagery

This section was aimed to explicate the work before rule-writing and modelling process. Surely, any modelling process may be detailed as much as work requires. As an output of GIS-based data creation part, adequate amount of data has been collected; parcels in the area (Figure 3.20), road centerlines (Figure 3.21) and terrain with satellite imagery (Figure 3.22). Parcel shapes will be used for modeling the buildings and any other elements within the parcel such as yards and pathways. Road centerlines will be used for road creation. All these urban elements will be conformed into terrain map to model on actual land-specific topography. In the following part, procedural modeling process in CE will be explained, in detail.

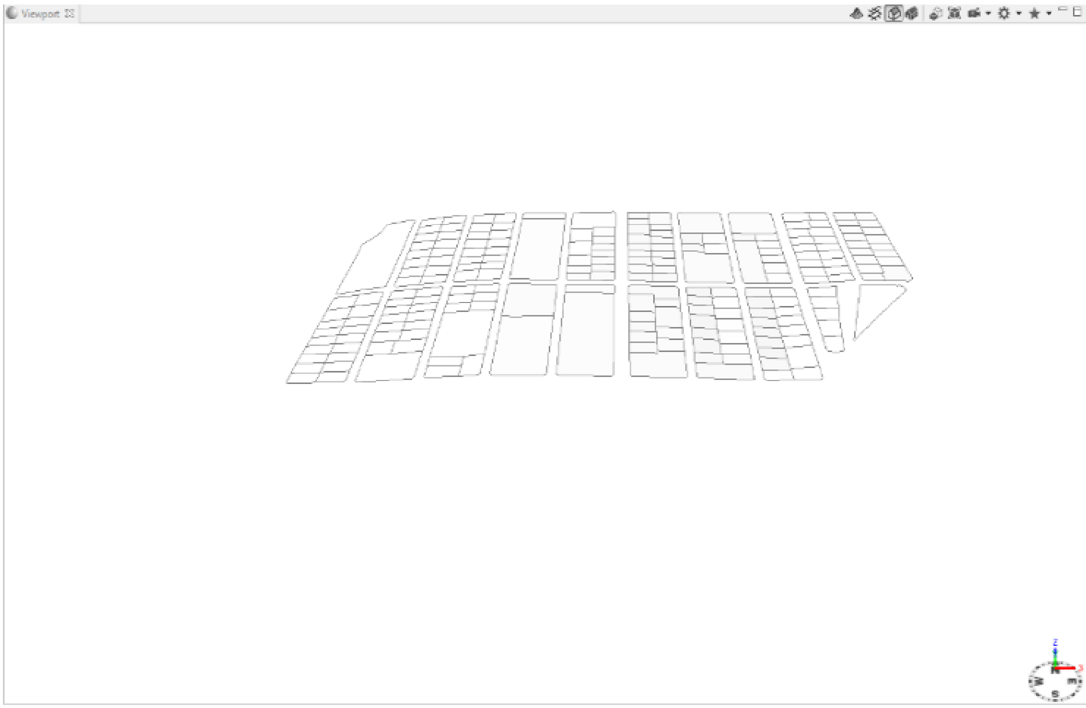


Figure 3.20 : Perspective view of imported parcels into CE.

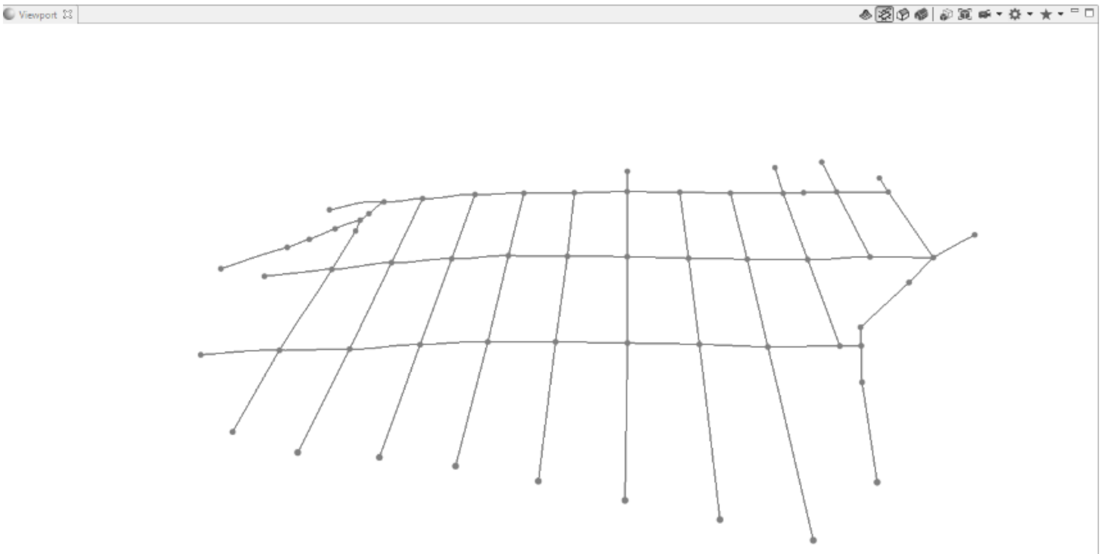


Figure 3.21 : Perspective view of imported road network into CE.

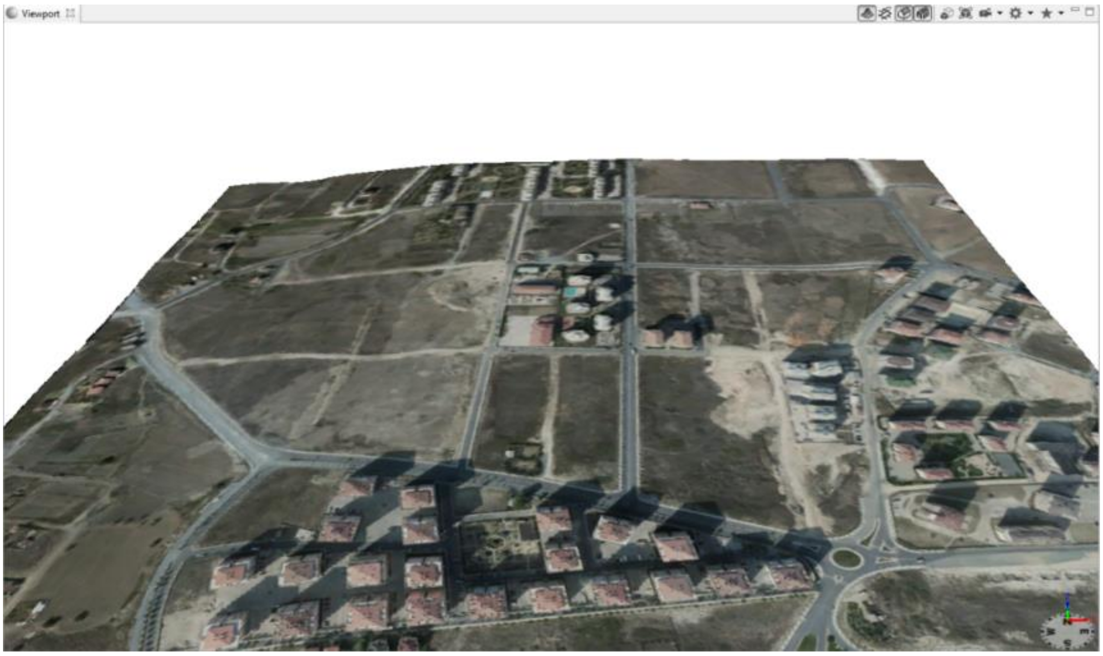


Figure 3.22 : Perspective view of imported terrain with satellite imagery in CE.

3.5 Rule–writing in Procedural Modeling

As reported before, procedural modeling in CE requires both shapes and operational algorithms to process these given inputs. Therefore, it allows users to define their own modelling principles. In this study, modeling is conducted on the software ESRI CityEngine Advanced 2015.2.

The main instruments of implementation plan are described previously. Using these instruments as restrictive factors, new rule files are produced. One of the crucial issues in the case study process is the procedural estimation of building footprints. The problematic of how to handle parcels into the buildings is one of the key concerns of the modelling process. Since urban design is mostly interested in assuring balance of solid – void relationships, intended urban modeling process should offer a system that allows diverse urban pattern choices. As previously mentioned, target rule structure in this study allows the creation of diverse alternatives within the boundaries of planning regulations. If the procedural rules provide a solid background for interactive editing phase, layout alternatives for all parcels would be designed easily with same operations. In order to handle both big and small parcels with the same procedural rules, a sequence of operations is defined. There are three main objectives of this workflow. First one is to create a procedural modelling structure that adhere to planning regulations. Second objective is to provide harmony in terms of design. Third and the last one is to create a realistic look and to avoid monotonous urban pattern that outsourced rules would create.

Building.cga rule is the main file that most of the parcels will use. The way that this rule operates is crucial so that it is written to meet instruments of implementation plan. Main workflow of the rule algorithm is tried to be depicted in Figure 3.23.

Building rule initially combs out non-typical-building parcels. If the parcel is designated with a zoning code such as green area, rule takes it out of the building construction procedures at first place. As mentioned before, way the rules work is transfusing parameters from predecessors to successors. It is possible that a predecessor shape generates more than one successor shapes with conditional rule syntax. Thus, according to specific rule parameters or shape attributes, linear operation stream can alternate at any step.

Before executing any geometric process, some fundamental parcel attributes are reported. At this step, parcel area is calculated and reported. Since it can be used on many steps for calculations, it is taken as constant value for each shape. Later, a critical calculation is made. Since *FAR*, *Coverage* or *Max_Floors* attributes brought by shape itself from GIS, CE needs a rule for determining the gross floor area that the plot is allowed to develop. As mentioned before, implementation plan has variety of styles rather than a particular style for indicating floor area limitations. Thus, calculation of allowed GCA is made by procedural rule.

Rule is basically inferring that if FAR is not given in the GIS-based shape attributes, to look for Coverage data. Then, area calculations are made using *Coverage* and *Max_Floors* attributes. If FAR is given, rule stores this constant value to use at the building construction phase. If somehow both Coverage and *FAR* value are found, rule relies on *FAR* value. Conditional rules always require “else” cases. In this case, if none of these attributes can be found on plan, a field is reserved to input manual GCA value, which is filled with results of external calculations. One of the key points of this ruleset is that once the *GCA* is determined, any of the following rules cannot change this value. This constant number is ensured to reach at the final design no matter how the layout, rotation, floor size or height of the buildings change.

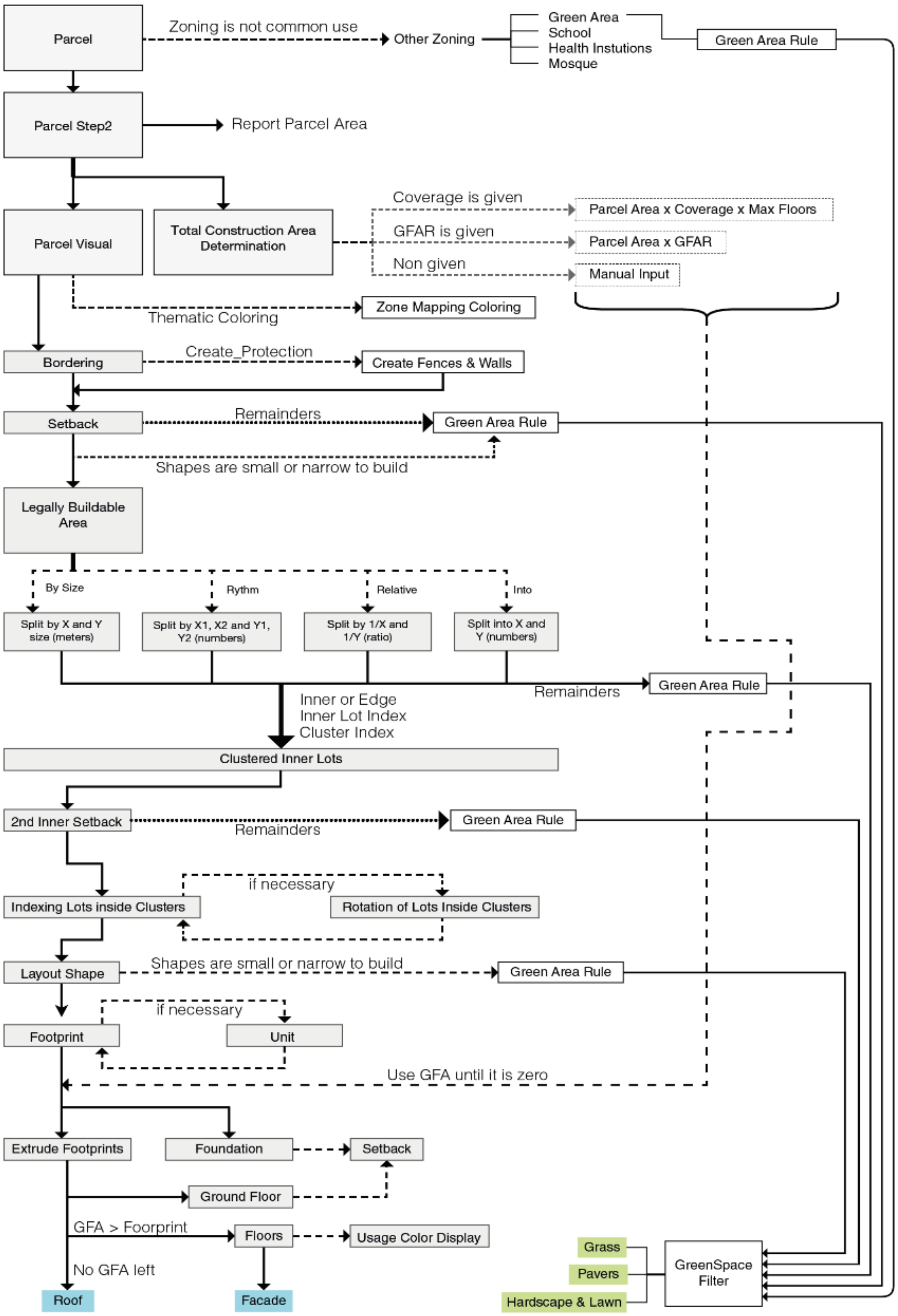


Figure 3.23 : Workflow diagram of Building rule.

3.5.1 Inner partitions

Until this point, no physical operations were defined. As the initial physical approach, building rule takes the initial shape and creates inner partitions, if necessary. First, rule splits initial parcel shape on X and Y axes iteratively, designates these splits as inner lots and defines virtual clusters of these lots (Figure 3.24). Then, rule continues on the execution by designation of predefined layout types on these clusters. Layout types appoint inner lots their specific building shapes. Thus, various layout characteristics can be assigned to plots according to their part on the grand scale design. Following parts depicts the details on the creation of partitions.

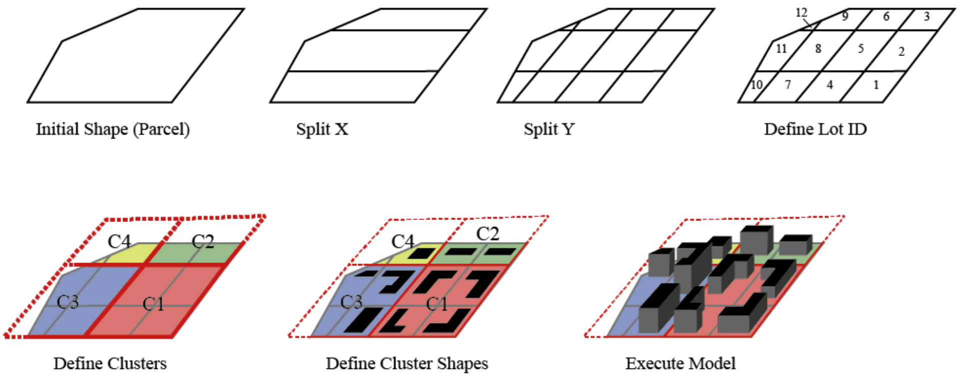


Figure 3.24 : Main clustering workflow of the rule Building.cga.

3.5.2 Bordering & setbacks

Setbacks are one of the first operations to develop a parcel. It is a common operation that most of the example rules execute at the first place. Building rule also executes the setbacks of the plot. As mentioned before, plan has signage on plots that show front, back and side setback values for most plots. Values have already been merged into shapes in GIS environment. Setback values are connected to layer attributes automatically as shown on Figure 3.25. Yet, one must keep in mind that any attributes such as these, can also be changed at the interactive modeling phase.

```
attr Front_Setback = getObjectAttr("Front_Setback")
attr Rear_Setback = getObjectAttr("Back_Setback")
attr Left_Setback = getObjectAttr("Side_Setback")
attr Right_Setback = getObjectAttr("Side_Setback")
```

Figure 3.25 : Layer attribute connector for Setback Values.

On the other hand, since Beylikduzu is one of the newly developing districts of Istanbul, new typologies of settlement are emerging. It is highly common in this area that plots to be developed as gated communities. Private communities mostly tend to build security walls, barriers or fences around the plot. This situation is not desired in terms of diversity, but current urbanization dynamics of Istanbul make developers to take security precautions, after all. In the next step of the rule executing pipeline, bordering and security barriers can be created if the switch is enabled in the interactive editing phase. User is also able to select the type (fences, walls, green walls etc.) of the bordering.

3.5.3 Small shapes

Next step of the pipeline is to check out the parcel dimensions. Actually, the situation that created successor shapes are too small or narrow to build is checked several times with the rule, as can be seen in Figure 3.23. Since implementation plans has restrictions about minimum size and dimensions, the rule ensures there will be no development on the plots that meet the specified value. Small Shape operation checks out given geometry if its area is smaller than a specific value or the scope of the geometry exceeds specified narrowness ratio. Narrowness ratio is an additional criterion that is the ratio of width and length of the current geometry. If the geometry does not meet specified requirements, it is marked as Green Area with the label of "Small_Shapes_GS". User can decide later on the modeling phase how to handle this type of green space -hardscape or landscape.

3.5.4 Splitting & parcelization

With borders and setbacks are finished, remaining space is legally buildable area. Yet, some of the parcels requires more than one building. Parcels are generally meant to be partitioned for single buildings but some of them are suitable for constructing more than one building. So that, parcels in Beylikduzu cover an area that is bigger just for one building to develop. Besides, plan articles and regulations define the conditions of multiple building developments in one parcel (Beylikduzu Municipality, n.d., Clause 13; Ministry of Environment and Urbanisation, 2014, Clause 25). Thus, there is a need for a set of criteria to create meaningful layouts inside parcel. Using split operation in CE, plots can be subdivided into a set of smaller shapes ("CityEngine Help", 2016). In this study, buildable areas can be split in various ways. In the rule file, 4 types of splitting methods are defined (Table 3.6).

Table 3.6 : Alternative parcel splitting methods.

Splitting Mode	Operation	Input Type	Required Fields
Size	Splits X scope by Xs and Z scope by Zs	meters	Xs, Zs
Into	Splits X scope into X and Z scope into Z	numbers	X, Z
Relative	Splits %X1 + %X2 repeatedly, %Z1 + %Z2	ratio	X1, X2, Z1, Z2
Rhythm	Splits X scope into X1 and X2 and Z scope into Z1 and Z2	numbers	X1, X2, Z1, Z2

In first case, rule splits X scope of the geometry by specified X size (in meters) repeatedly, starting from a certain corner. Then, same execution is repeated for Z scope (Figure 3.26). Dimensions of inner plots are absolutely *X x Z.* Remaining parts at the edge of plot are left as they are.

Figure 3.26 : Split by Size Example.

Second splitting method splits the geometry *into* number of parts. In this method, rule splits the shapes absolutely into specified number (as X1 and Z1 attributes in Figure 3.28) of new shapes. This method creates equal-size shapes, leaves no gap at the edges. However, the size of new shapes is not absolute and they cannot be specified in this method.

Using *relative* splitting method, user can create inner shapes in non-uniform styles. For example, in Figure 3.27, parcel scope is considered as 10 units and X scope is split into three pieces as 5/10 – 1/10 – ~5/10 of the whole geometry. Same relative split operation is made for Z scope of the geometry with specified attributes. Relative split method gives user the ability to use ratios between geometric shapes in order to create a certain layout.

Figure 3.28 : “Split Into” Example.

Figure 3.27 : “Relative Split” example.

Similarly, *rhythm* split method creates a repetitive pattern of splits and creates a recognizable pattern. Both relative and rhythm split methods creates two kinds of shapes that can be distinguished as construction lot and green area. User can define buffer areas between buildings as green spaces and can adjust the size of construction area and green area lots according to general design framework (Figure 3.29).

Split modes are important since this step designates the areas of development at the first place. Having chance to choose one of the four methods gives modeler flexibility to adjust placement and size of the inner building lots. With the size and rotation

Figure 3.29 : “Rhythm Split” example.

factors taken into account, this step is crucial in terms of design quality and diversity. According to plot geometry, modeler can select one of the pre-defined splitting styles and provide input parameters to define partition layout. If the parcel size is enough to only build one building, user can skip splitting part by selecting *Split Into* method and provide the parameter of 1 for the split numbers.

3.5.5 Lot indexing

Rule is written to label created inner partitions according to their placement within the parcel. An indexing system is defined that subsequent operations can distinguish lots individually. Every split mode has codes to pass over split index parameters to its successors. According to split size and plot scopes, rule defines a series of numbers for both dimensions (X and Z) starting from a certain corner (Figure 3.30). Rule also stores the information of the last split created and labels that number as Index Total. When shape is passed into subsequent operation, all created inner lots have an identifier index as *"X Index, X Total, Z Index, Z Total"*. Thus, that information is passed over all successor shapes in order to ease the selection of desired lot when needed.

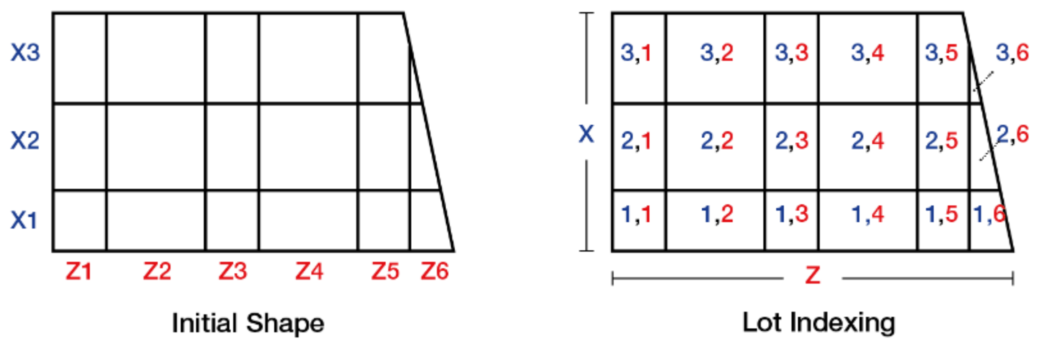


Figure 3.30 : Inner lot indexing strategy

At this step of the rule execution, a second setback and a lot buffer within created inner lots is defined. These operations answer the purpose of dividing buildings apart or sticking them together (Figure 3.31). Since most of the plots has a regulation for detached building layout, inner lot setbacks and buffer functionality is defined when coding the rule. However, a continuous or attached design requires no buffer or setbacks between buildings. Implementation plan also have regulations for attached layout in some parts. In such cases, rule allows to give no space between buildings, so a continuous design or attached buildings can be created.

3.5.6 Clustering

Clustering is one of the most important steps of rule execution pipeline. After setbacks and buffers executed in inner lots, outward bounds that building footprints can be placed in are designated. In this step, rule needs a framework to create pre-defined layouts. Previous steps have split the geometry into smaller inner lots and applied necessary setbacks into those lots. Figure 3.33 depicts an example; total number of 29 lots are created with splitting rules in Step 1. Clustering rule picks out specific lots and assigns them as a parameter (e.g. “C1”) to group them together virtually. Cluster system defined in this rule study has four lots in each cluster. So, step 2 of Figure 3.33, shows the identification of four lots. Following this parameter assignment, lot indexes are replaced by a quart-based index system. This new indexing assigns lot numbers at the range (1,2,3,4) in each cluster. Since, from this step on the position of lots within whole geometry is not important. Thus, lot indexes give place to cluster indexes (Figure 3.33, 3).

Figure 3.31 : Comparison of layouts with and without setbacks

Rule includes five types of pre-defined clusters; O-Shape, U-Shape, L-Shape, All Front and Total Areas. Selecting one of these types of clusters triggers 4 subsequent operations after. For example, an O-Shaped cluster includes 4 L-Shaped layout rules. Similarly, a L-Shape cluster brings out an L-Shape layout on a corner, two I-Shape layouts on cross-sides and a blank lot which then refers to Green Space rule. A U-Shape cluster refers to two facing L-Shape layouts and two facing I-Shape layouts

(Figure 3.32). If “All Front” cluster is selected, four I-Shaped layouts are created which can be oriented into same various sides. Last predefined shape is actually an else case which does not apply any kind of layout definition but leaves the shape as “Total Areas”.

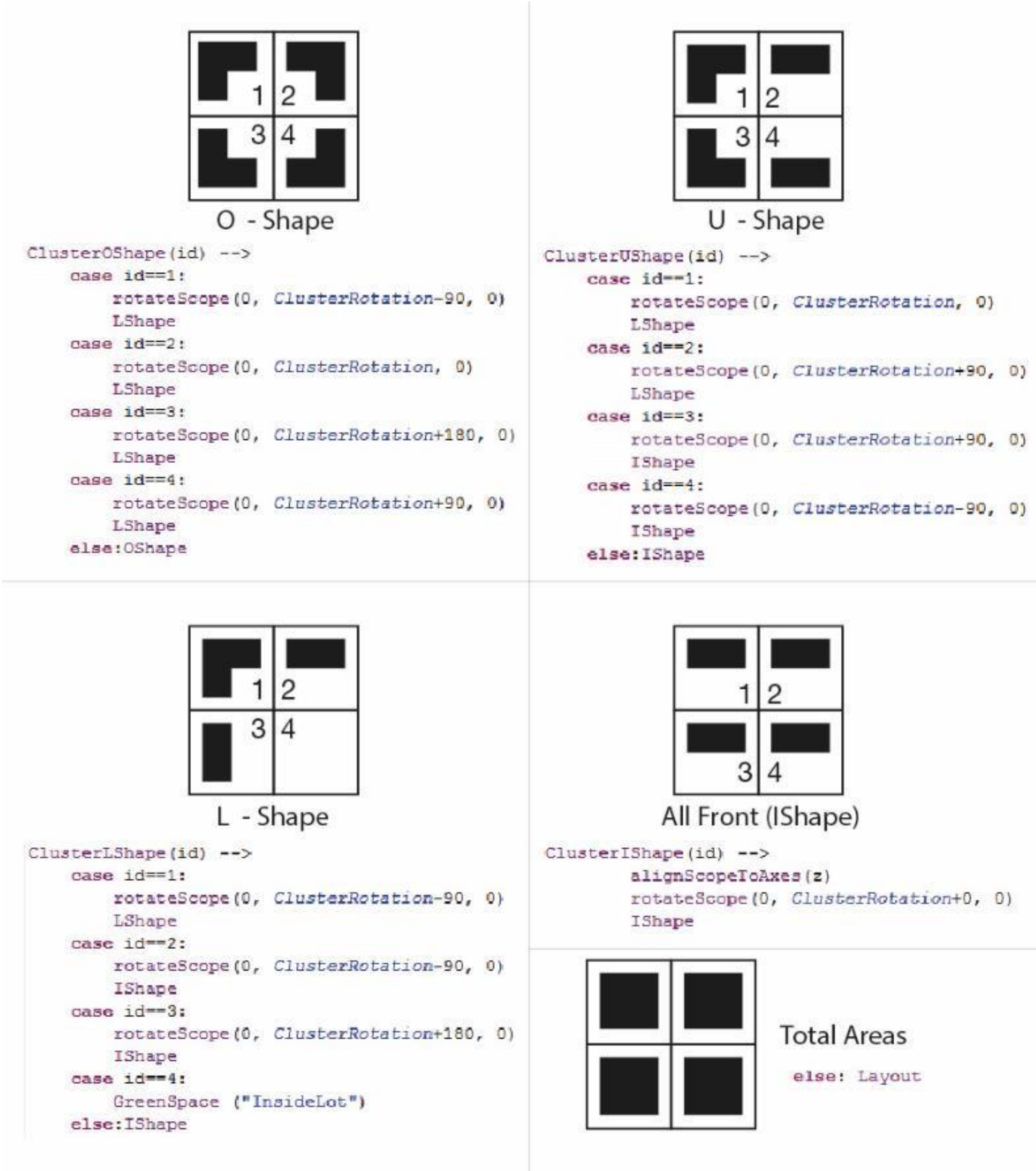


Figure 3.32 : Cluster style assignments.

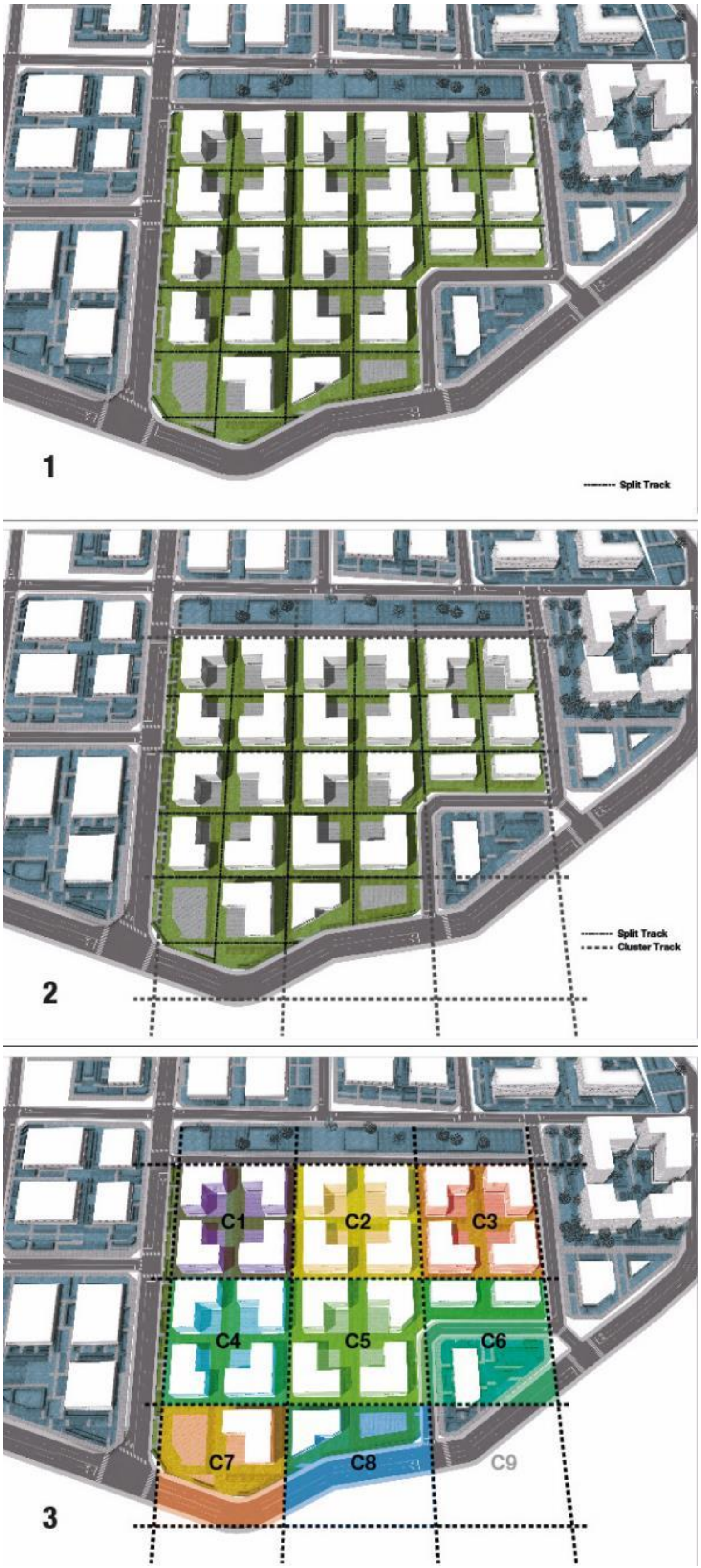


Figure 3.33 : An example implementation depicting principles of clustering.

3.5.7 Cluster rotation and shuffling

The rotation of clusters as a whole and as individual buildings is an important issue. Defined cluster styles can be rotated and transformed. Using procedural operations, pre-defined building layouts can be rotated individually. In particular, by using *rotateScope* operation with the *ClusterRotation* parameter, inner rotation of layouts within clusters can be translocated. This workflow adds one more step forward to achieve design flexibility.

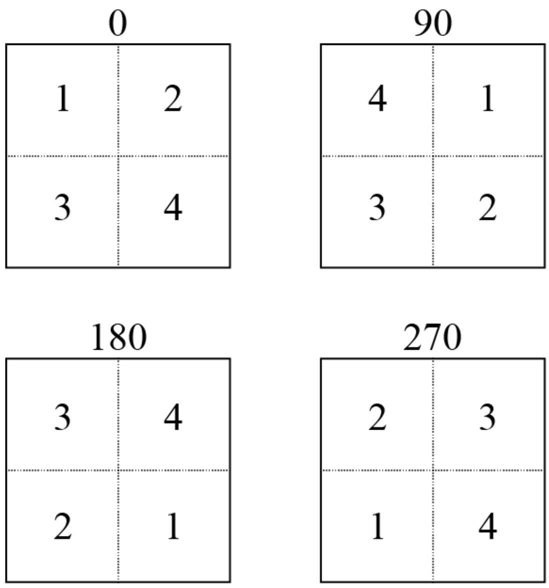


Figure 3.34 : Cluster Reset (Re-indexing).

Similarly, clusters can be rotated as whole to adapt general intended layout of plot, too. Rule file simply changes indexes of four inner lots to rotate cluster, when triggered (Figure 3.34). Using these both operations, design of the plots can be controlled hierarchically. By choosing different clustering options, modeler can create a design framework for the whole plot; which is in relationship with neighboring plots.

With clustering done, all inner lots are assigned with their associated layout shapes. Layout is basically the shape that buildings will be extruded in. According to specific situations, layouts can be left as blocks (Figure 3.35, upper left), or they can be split into units. It is controlled by “*Create_Units*” switch and “*Unit_Width*” parameter. On the upper right corner of Figure 3.35, units are created with 15 meters width. An additional operation enables user to offset units by specified distance. On the lower left side, a 7-meter distance is applied to units and “*Offset_Mode*” parameter is set to “Increasing”. So that 15-meter wide units which have increasing offset at 7 meters in total. Various offset modes are defined in this study and much more can be created. On the lower right corner, unit offsets are applied in Alternating mode.

3.5.8 Footprint to building

With the final footprint shape is determined, rule creates a copy for foundation and forwards the shape to the Footprint rule. Foundation and ground floor are handled with a different rule because most of the buildings will need a setback on ground floor. It is common in Turkey planning system has definitions about setbacks in ground floor. Actually, regulation defines the setback in the reverse way since it allows to build overhangs in some situations. Yet in this study, ground floor setbacks are enabled. User can provide an input value in this step, according to parcel-specific overhang regulations.

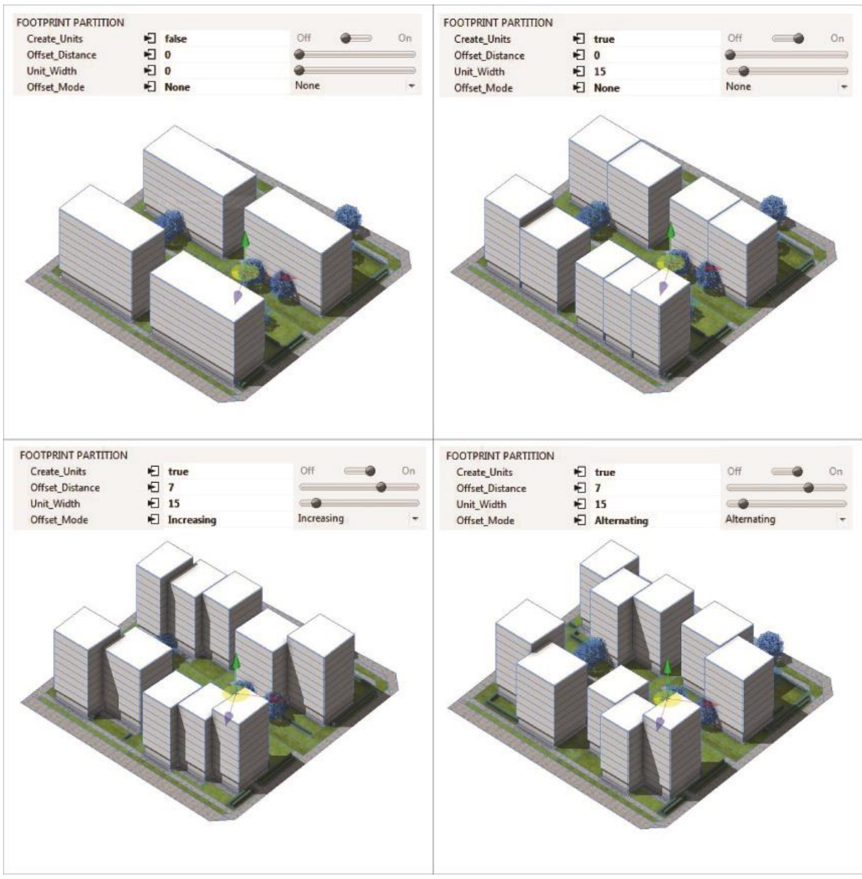


Figure 3.35 : Creating unit layouts.

Footprint rule has a recursive structure that uses construction area parameter, adds floor footprints until construction area in hand is zero. Construction area was calculated at first steps which the geometry was in its simplest state. Using this parameter, Footprint rule creates floor footprints and then forwards the geometry to the same rule recursively. It has a conditional rule structure that checks the geometry parameters and behaves according to information of the current geometry (Figure 3.36). If construction area is bigger than the current footprint, it checks if floor index is 0. If it is 0, it forwards a duplicate of the geometry to Ground Floor rule, sets the current floor index to 1 and forwards the shape to beginning again. If the construction area is bigger than footprint area again and floor index is 1, rule transforms the shape on top of the ground floor, constructs the floor and sets the current floor index +1. This operation repeatedly continues until construction area is exceeded. In this case, rule forwards the shape to roof construction rule. This rule is designed for reaching a specific GCA value which will call itself out until a criterion is met.

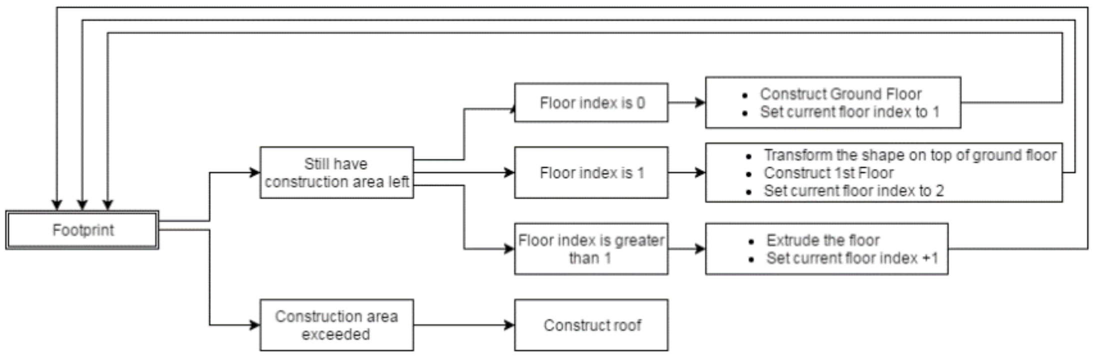


Figure 3.36 : Footprint rule operation diagram.

3.5.9 Further rule-writing

This study mostly covers the procedure of layout creation within plan plots. Thus, other rules such as façade creation, greenspace and landscaping procedures or streetscape rules are adapted from outsourcing. There are plenty of example scenes on ESRI ArcGIS website ("CityEngine Examples", 2016). ESRI also presents lot of examples which includes rules and scenes. Many of the supportive rules used in this study are migrated from the case study named “Redlands Development” (ESRI, 2015).

As previously mentioned, rules can be individually created according to their purpose. As listed in Table 3.7, plenty of various rules are used in this study in order to distribute the workflow into separate rule operations. As seen in the Figure 3.23, at the end of the rule operation pipeline, shapes are finalized as in various forms such as Façade, Roof or Green. These types of shapes are continued by external operations in their according rule files. With the help of this kind of distribution, flexibility and efficiency of rule system can be constituted.

3.5.9.1 Thematic mapping

3D-GIS based urban models meant to be information rich. In this study, output urban models will have the ability to deliver information of zoning, usage or plenty of numeric information. Models can represent these types of information based on the criteria defined on rules. In this case, users can view the model as thematic maps. This kind of visualization allows viewers to interactively observe zoning, allowed usage distribution of each floor of buildings with realistic (textured) or simplistic (colored) look.

Table 3.7 : Summary of rule files created on the case study.

File Name	Usage
Building.cga	Main rule file to create development on plots.
GreenSpace.cga	To model all the open spaces including hardscape and greenspaces within the city.
Zoning.cga	Includes zoning classifications and calculations.
Facade.cga	Create facades out of the buildings that are created by Building.cga
Special Buildings.cga	Importing and placement of other zoning types.
Building Performance.cga	Includes environmental calculations and constant values for performance reporting.

In this part of rule workflow, Parcel Visual rule ensures that if Thematic Mapping parameter is enabled, plots will be colored (in 2.5D) in order to their functions on plan. Rule provides opportunity to map the zoning both when the plot is modelled and when it is simple shape. Additionally, rule algorithm is designed to be able to show every element to be colored according to their usages. Thus, each floor in the selected area can be displayed in respective colors of each usage category, without textures.

3.5.9.2 Special buildings

This rule-writing workflow covers the generic zoning codes. In other words, this modeling process is applicable only to common usage types such as residential, commercial or office. However, other than generic buildings, city is meant to have specialized building that do not fit a zoning code. Those types of usage areas are needed to be modeled in some way. Although other land use decisions can be modeled by using an altered version of the same algorithm, it would take less time to use static models within this procedural framework.

For example; religious places, schools, sports areas, hospitals are irregular typologies that would take long time to model using written codes above. For representing these type of land uses, CityEngine’s import function is employed with some additional rules. The workflow of the code is simple. User can define setback values and remainder area inside the parcel, initially. After rotate and placement parameters are also set, Special Buildings.cga rule measures remaining area and imports a static 3D models from one of the predefined ones with suitable size.

3.5.10 Summary of preliminary studies

One of the main objectives of rules is to provide flexible design tools that provide opportunities to edit both macro scale entities and details as much as possible in the interactive modeling phase. Rules are created to define a backbone for the interactive editing phase of procedural modelling applications. By using rule algorithms, variety of tools are defined in order to be used in editing phase. Table 3.8 lists the created parameters within this rule algorithm and compares those parameters with regulative ones.

Rules define a set of hierarchical operations until a desired state of geometry is accomplished. As previously depicted in Figure 3.23, each step of rule execution defines a single or alternative ways to deal with current geometry. Still, rules do not define a certain end-product for every geometry. Yet, rules can be designed to display geometry in any desired state. In case of this study, produced models can be displayed realistic with textures, partly textured, thematically colored or not colored at all.

One must keep in mind that many operations defined in this step are not compulsory to be executed. Nearly all defined operations such as clustering, splitting, setbacks can be skipped during the process of interactive editing. So, previous section reported the generation of a custom operational pipeline that is not necessarily place-specific. This rule can be utilized on any place, with custom attribute values.

3.6 3D-GIS based Procedural Modeling and Finalization

In the second step of the modeling process, prepared rule algorithm will be applied on the actual GIS-based shapes. By interactively editing the parameters defined in the rule-writing process, design iterations will be created. After the finalization of alternative designs, a quantitative comparison of designs will be conducted.

3.6.1 Interactive editing phase

Since “shape to rule file” integration has been made in ArcGIS, rule files were associated to shapes automatically. After the rules are applied to associated shapes, there is need for editing the parameters of each shape. If the rule parameters are not edited in this step, still a model will be generated with the default parameters that is used in the rule file. Shape parameters can be either edited individually or as groups. In this part, plots are manually post-processed to meet the requirements of objectives of this workflow. Analytic information about selected case area were given previously. In the following part, process of designing and finalization of the case area will be explained.

One must keep in mind that although this process is simplified and altered to be able to interpret to the reader as in steps. Actual working principle of procedural modeling is much more complex process. In fact, when rule is first applied to the shape, CE automatically generates the final model that is defined by the default parameters and attributes in the rule file. While alterations and edits are made in parameters, CE automatically updates the final model within the chain of operations in the rule file. This means that if a single parameter such as side setback, can change whole model; e.g. total number of floors, building height, layout of the building etc. Yet, to be able to make it convenient and focus on the design logic, model editing will be explained as in steps.

Although some attributes such as *Max_Floors*, *FAR* etc. are brought by the shapefile itself, some shape-specific attributes are edited in CE. These attributes are mostly parcel-specific ones such as split mode, split size and layout based attributes like cluster and rotation. Indeed, there is no doubt that plan gives enough flexibility to offer infinite number of alternative layouts for each parcel. Thus, a general design principle is needed to be developed for the area in order to create alternative designs

Table 3.8 : List of parameters in Building.cga rule.

Group	Parameter	Range	Default Value	Related Regulation Clauses
DENSITY & ZONING	FAR	0.4 – 3	0	Plan, BDPA (16.4), BIPN (23.4, 28, 29, 30)
	FAR Multiplier	0.5 - 2	1	BDPA (5,7,9), BIPN (23.2, 23.4, 23.5)
	Manual FAR Target	0 – 100,000	0	-
	Coverage	0.4 – 1	0	Plan, BDPA (16.2), BIPN (23.4, 23.5)
	Max Stories	1 - 25	0	Plan, BDPA (16.10, 29)
	Height Max	3 - 80	0	Plan, BDPA (16.10, 29)
ZONING SETBACKS	Front Setback	5 – 20	5	BDPA (6, 16.6, 18.1), BIPN (23.1)
	Left Setback	3 – 20	3	BDPA (6, 16.6, 18.2), BIPN (23.1)
	Right Setback	3 – 20	3	BDPA (6, 16.6), BIPN (23.1)
	Rear Setback	3 – 20	3	BDPA (6, 16.6), BIPN (23.1)
PARCELIZATION	Rotation	(-90) – 90	0	-
	Split Method	By Size, Into, Relative, Rhythm	By Size	BIPN (12.2)
	X_Size	14 – 50	30	BIPN (12.1, 12.2, 13)
	Z_Size	14 – 50	30	BIPN (12.1, 12.2, 13)
	X Offset	0 - 15	0	-
	Z Offset	0 – 15	0	-
	X1	0 – 10	0	BIPN (12.1, 12.2, 13)
	X2	0 – 10	0	BIPN (12.1, 12.2)
	Z1	0 – 10	0	BIPN (12.1, 12.2)
	Z2	0 - 10	0	BIPN (12.1, 12.2)
CHECK	Minimum Lot Dimension	6 - 10	10	BDPA (17), BIPN (15.1, 23.1)
	Parcel Scope Check	true, false	true	BDPA (17), BIPN (15.1, 23.1)
	Layout Scope Check	true, false	true	-
BUILDING INNER SETBACKS	Front Setback	0 – 10	0	BDPA (6, 16.6, 25), BIPN (23.1)
	Back Setback	0 – 10	0	BDPA (6, 16.6, 25), BIPN (23.1)
	Left Setback	0 – 10	0	BDPA (6, 16.6, 25), BIPN (23.1)
	Right Setback	0 – 10	0	BDPA (6, 16.6, 25), BIPN (23.1)
	Setback Mode	None, GF Front, GF All Sides, GF 3 sides	None	BDPA (36); BIPN (7, 8)
	Setback Distance	0 – 2.5	0	BDPA (16.50, 36), BIPN (7)

Table 3.8 (continued) : List of parameters in Building.cga rule.

Group	Parameter	Range	Default Value	Related Regulation Clauses
CLUSTERING	C_n Buildings	0 - 4	4	-
	C_n Reset	0, 90, 180, 360	0	-
	C_n Rotation	0, 90, 180, 360	0	-
	C_n Type	U-Shaped, All Front, L-Shaped, O-Shaped, Total Area, Not Build	Total Area	BDPA (16.55, 25)
FOOTPRINT PARTITION	Create Units	true, false	false	-
	Building Depth	7 – 40	13	BDPA (16.7, 27, 28)
	Offset Distance	0 – 10	0	-
	Unit Width	7 - 25	13	BDPA (16.7, 27, 28)
	Offset Mode	None, Increasing, Decreasing, Alternating	None	-
DISPLAY	Transparency	0 – 1	1	-
	Display Façade Textures	true, false	true	-
	Display GreenSpace Textures	true, false	true	-
	Thematics	Off, Cluster, Usage, Zoning	Off	-
ZONING SETBACKS GREENSPACE TREATMENT	Front Setbacks	Pavers, Grass, H&L,Parking, Random	Random	BDPA (16.33)
	General Setbacks	Pavers, Grass, H&L,Parking, Random	Random	BDPA (16.34, 16.35)
	Split Leftovers	Pavers, Grass, H&L,Parking, Random	Random	-
	Inner Lots	Pavers, Grass, H&L,Parking, Random	Random	-
	Small Shapes	Pavers, Grass, H&L,Parking, Random	Random	-
	Inner Setbacks	Pavers, Grass, H&L,Parking, Random	Random	-
BUILDING HEIGHT	Upper Floor Height	2.5 – 5.5	3	BDPA (16.11)
	Ground Floor Height	2.5 – 5.5	3.5	BDPA (16.11)
	Foundation Adjustment	-10 - 10	0	BDPA (16.8, 16.12, 16.31, 26, 30, 31)

Note: Related Regulation Clauses include the regulation and related clause numbers in parenthesis. BDPA refers to "Bylaws on Planned Areas", and BIPN refers to "Beylikduzu Implementation Plan Notes".

3.6.1.1 Alternative A

In the first alternative, units are intended to be clustered around courtyards as much as possible. Main principle of this design approach is to set minimum front setbacks to provide larger areas on the courtyards. The aim of this approach is to constitute meaningful spaces on the inner side of buildings.

Although small parcel subdivisions decrease the number of alternatives in some areas, layout of small parcels are designed according to general framework of their close surroundings. Following, both small parcels with one buildings and big parcels that require multiple buildings will be demonstrated.

For example, Figure 3.37, A shows an single parcel that would not allow to build a single building. This parcel was initially processed with 5 m. setbacks in every sides. Since the aim of this alternative is to create inner courtyards, multiple splits are required on both dimensions. By providing adequate size of split values, 12 inner partitions were built in order to form O-Shaped clusters out of them (Figure 3.37, B). Later, 3 O-shaped clusters are created with 4 m. inner setbacks and 11 m. building widths. Units are not created in this parcel; buildings are left as solid L-shaped blocks (Figure 3.37, C). Footprints are automatically extruded to their provided heights, according to their position such as ground or upper floor (Figure 3.37, D). As previously mentioned, gross floor area of the parcel is allotted into separate units. In a hierarchical fashion, GCA value is distributed equally into building footprints, and then footprints distribute their share into floors. Hence, number of floors may not always match with the *Max_Floors* regulation. Procedural algorithm creates adequate number of floors for each building, which do not exceed the regulation maximums and use GCA value at full blast (Figure 3.37, E). After the buildings are extruded to their final heights, facade rule can be triggered with an on/off switch to add windows and necessary elements. For a realistic view, roof and façade is textured with pre-defined materials (Figure 3.37, F).

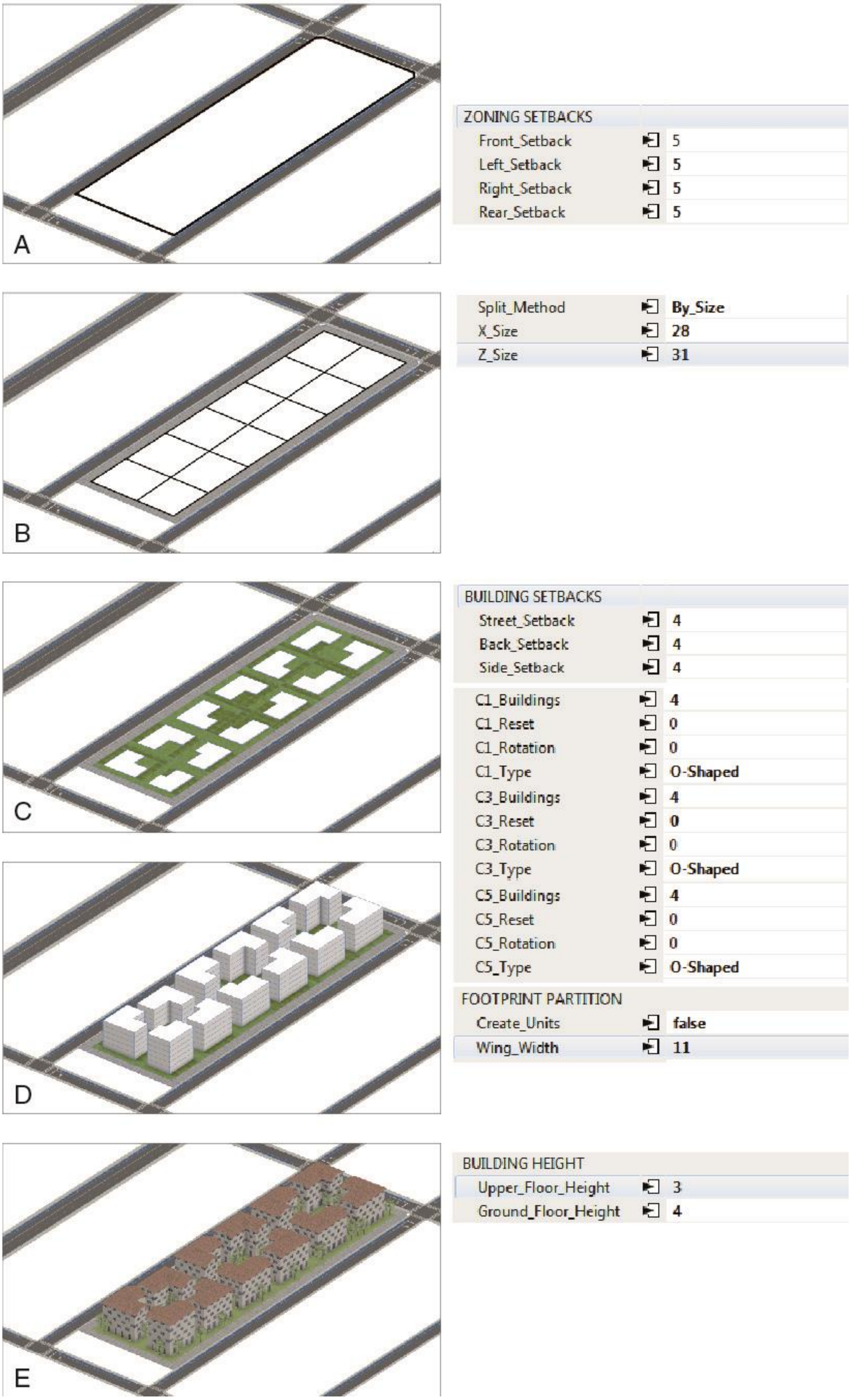


Figure 3.37 : Editing large parcels in Alternative A.

In the second approach, design process of a block consisting of small parcels will be explained. For example, Figure 3.38, A shows a block from the area which have 13 parcels in it. Total area of the parcels is 12.754 m^2, while average size is 981 m^2. At first, similar to previous example, FAR value for each parcel is calculated. This is the initial operation for the rule file, as previously mentioned. In cases like this, a presumption is made which block area is already split into necessary partitions. Therefore, after the setbacks are applied, no further split operations are conducted in the parcels (Figure 3.38, B). Since parcels have little space to locate the building, there are limited number of alternative layouts for these parcels. Yet, since the aim of this alternative is to provide inner clusters within building groups, building footprint layouts are organized in order to form 3 inner courtyards within the block (Figure 3.38, C). By using individually calculated FAR values, building floors are created (Figure 3.38, D). Last step is again façade and roof creation (Figure 3.38, E). Since the parcels are individually selectable, window placement alternatives, roof and façade textures can be selected individually.

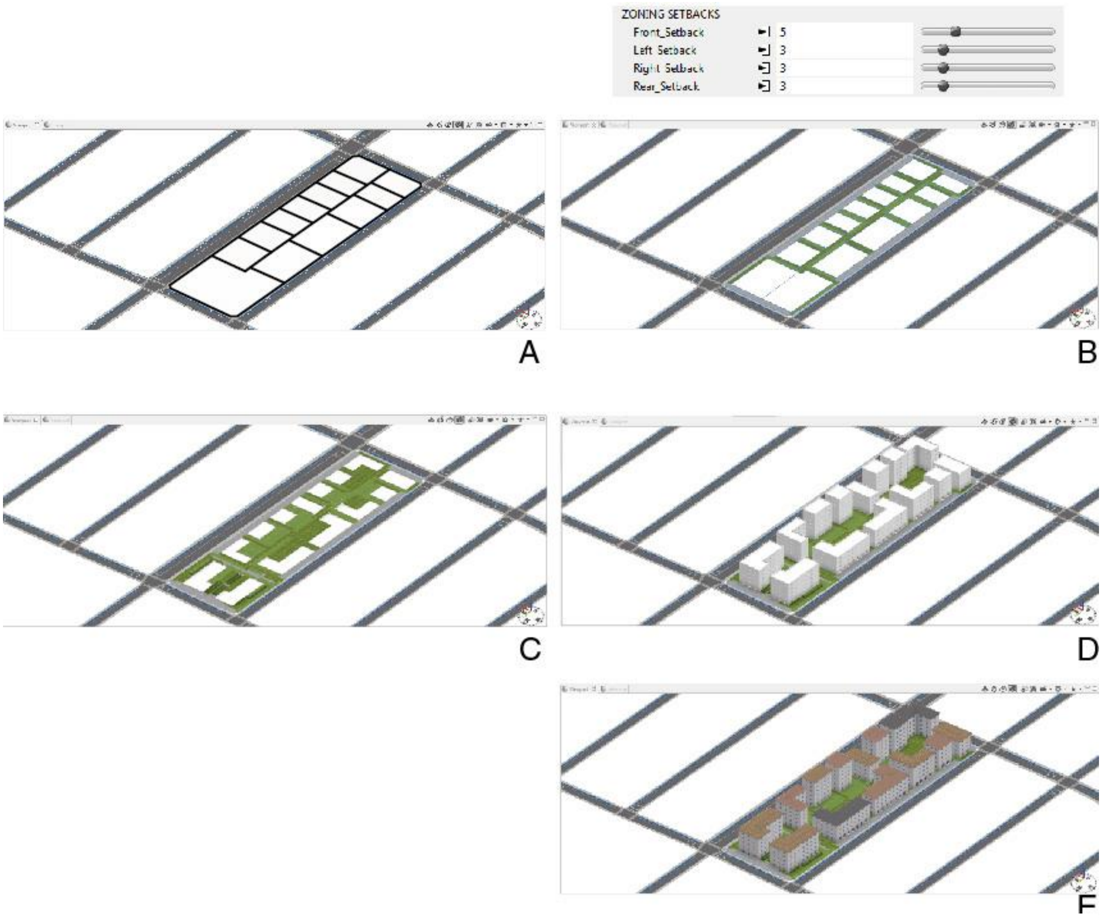


Figure 3.38 : Editing small parcels individually in Alternative A.

By using before mentioned techniques, 212 parcels in the area is modeled according to clustering principles (Figure 3.39, Figure 3.40). The size and dimensions of the clusters depend on the size of the surrounding buildings. Mainly, design of this alternative is based on a green system of interconnected courtyards. Development in each parcel will be using the right of construction area at full. Thus, after the main shape of the cluster is defined, the size of the courtyards is defined by width and depth of surrounding buildings.

Figure 3.39 : Final master plan of Alternative A.

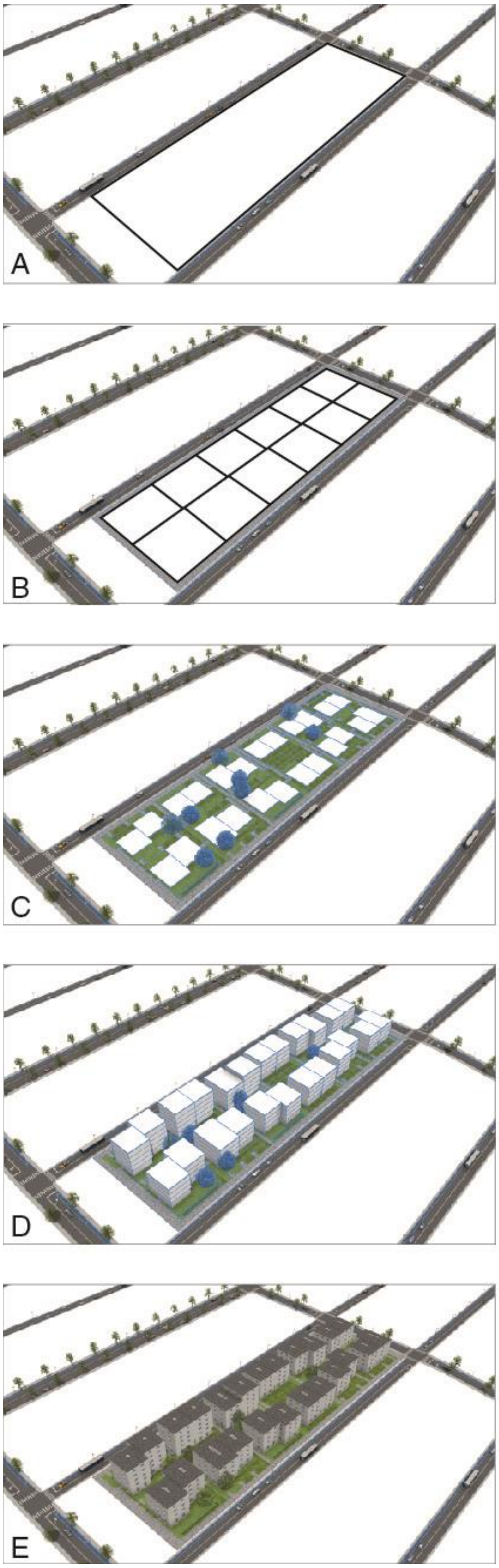
Figure 3.40 : Perspective view of alternative A.

3.6.1.2 Alternative B

In the second alternative, design is based on sequential placement of buildings in a row. Main principle of this alternative is to create a partitive layout. By partitioning the building into units, a dynamic layout is created. Taking a departure from the linear block layouts, a waving layout is designed which buildings are in tandem with each other. By defining a minimum limit of width, various units are created within single parcels which fulfil dimensional requirements. For the design demonstration process, approach on two example cases will be explained as in the first alternative.

Figure 3.41, A shows an example large parcel in the area. After the necessary setbacks are done, parcel is split into a number of inner partitions by the size of 30 x 31 meters (Figure 3.41, B). With the provided *Footprint Partition* parameters, two units on each partition with the width of at least 12 meters is created. The depth of all the buildings are 14 meters and they randomly offset to each other with distance of 3.8 meters (Figure 3.41, C). Since one cannot provide different *Offset_Mode* attributes to each cluster, offset is made randomly. That means a slight difference is expected in the layout, in each model generation. To restrict this randomness to some extent, cluster types and rotation parameters are changed (Figure 3.41, D). According to this parameters, rotation of the middle cluster is altered to opposite direction in order to provide continuity in the curvature line. Building setbacks are set to 3 meters on the front and back side and 3.8 meters on the right and left side of the cluster partitions to be able to provide better placement of the units. Lastly, model is finalized with textured facades and roofs (Figure 3.41, E).

Second example of Alternative B is a block of parcels in the study area (Figure 3.42, A). With the setbacks are applied, no further partition is necessary in these parcels. In order to skip partitions, *Split_Mode* is set to *Into* mode and X1, Z1 parameters are set to 1 (Figure 3.42, B). Since each parcel is a separate entity in this case, various front setbacks are provided on the inner side of the regulation-based setback (Figure 3.42, C). Cluster settings are set to *All Front* in all parcels. Figure 3.42, D shows the extruded buildings with the particular parameters of *Building Depth*, *Offset Distance*, *Unit Width* and *Offset Mode*. All of these parameters processed individually for the best placement and the closest usage of construction area limitations. Lastly, façade and roof style parameters are individually processed for a random look (Figure 3.42, E).



ZONING SETBACKS	
Front_Setback	5
Left_Setback	3
Right_Setback	3
Rear_Setback	3
PARCELIZATION	
Rotation	-2
SplitLook	false
Split_Method	By_Size
X_Size	30
Z_Size	31

FOOTPRINT PARTITION	
Create_Units	true
Wing_Width	14
Offset_Distance	3.8
Unit_Width	12
Offset_Mode	Random

C1_Buildings	4
C1_Reset	90
C1_Rotation	90
C1_Type	All Front
C3_Buildings	4
C3_Reset	270
C3_Rotation	270
C3_Type	All Front
C5_Buildings	4
C5_Reset	90
C5_Rotation	90
C5_Type	All Front

BUILDING SETBACKS	
Street_Setback	3
Back_Setback	3
lLeft_Setback	3.8
lRight_Setback	3.8
Street_Setback_Mode	Ground Floor Front
Street_Setback_Distance	0.7

Figure 3.41 : First approach to Alternative B.

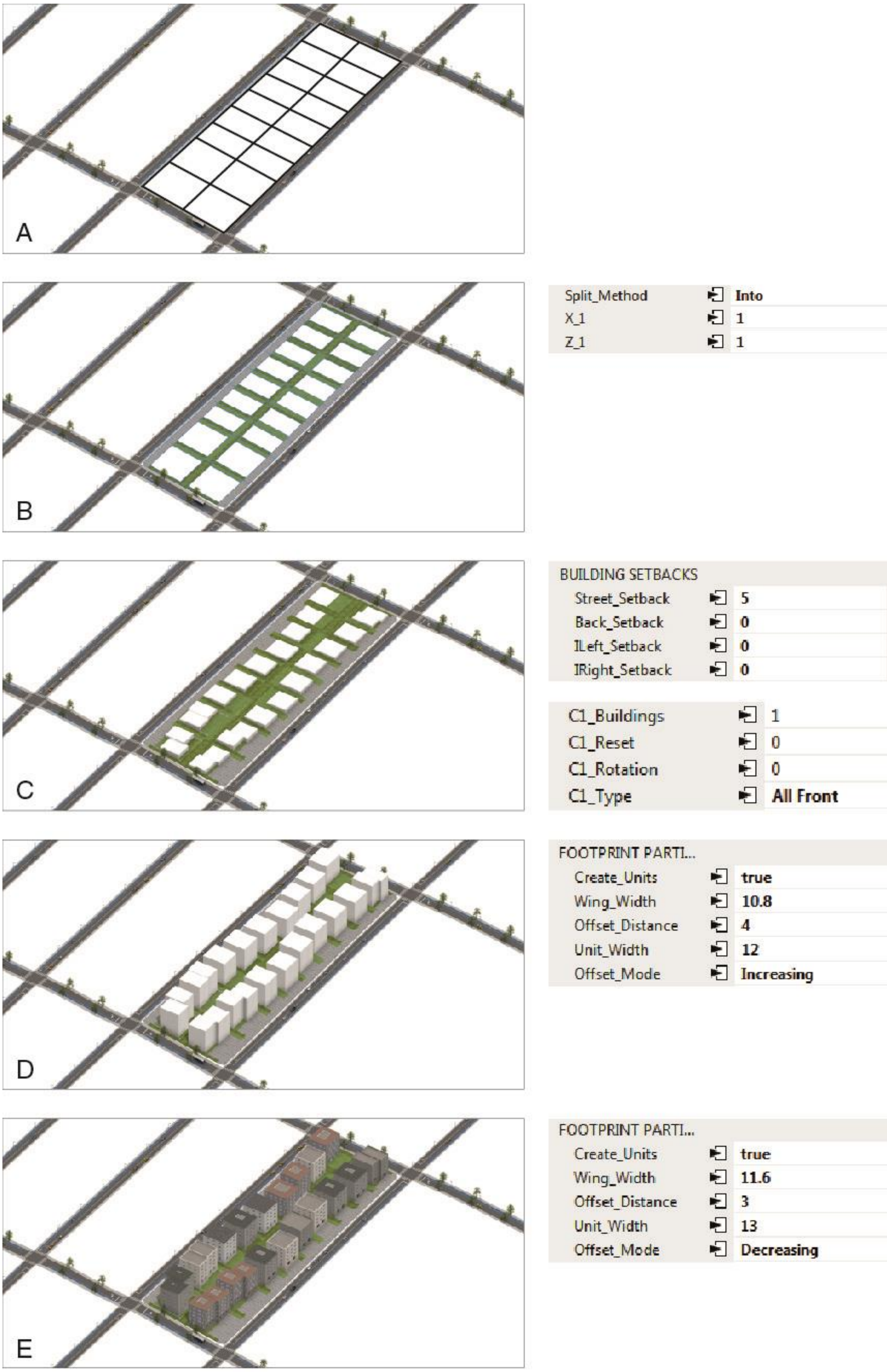


Figure 3.42 : Second approach to Alternative B.

By employing these two approaches, all of the parcels in the area are modeled. Figure 3.43 shows the final master plan that is designed with the principle of creating continuous linear building layouts within blocks. This design approach ensures alterations in the street section. Larger setbacks on the front side of buildings ensure widening street sections, while narrowing the backyards of the buildings. In contrast, smaller front setbacks create opposite results. By using these typologies, a dynamic but repetitive urban layout is designed (Figure 3.44).

Figure 3.43 : Final master plan of Alternative B.

Figure 3.44 : Perspective view of Alternative B.

3.6.2 Deliberation and reporting

Two different alternatives ensure that by using a single dataset, various design iterations can be created. Experiments on both alternatives provide a basis for comparison. In the following part, common facts and differences between two alternatives will be deliberated.

Parcel size is an important factor in terms of time and model detail. Although PM is proved to be a time-saving tool for urban modeling, still requires significant time to model a large area. Particularly in this study, it took significantly more time to model the shapes that do not require splitting and clustering.

Study showed that when parcel sizes are getting bigger, modeling is getting easier. As in Alternative A, using predefined layouts for clusters and batch editing provide savings in time. Yet, creating clusters from small parcels takes longer time. Similarly, modeling small parcels in Alternative B took more time than modeling large parcels. However, although this process takes more time to select and change values individually, it gives randomness in the appearance.

On the other hand, modeling times of two alternatives also differ. It took 6 hours to model entire area in Alternative A. On the other hand, modeling of Alternative B took 8.5 hours since units had to be manually aligned by a curvature. One of the most time consuming issues is the precise adjustment of regulative limits. Although the rule was designed to comply with the regulation at some point, some parameters are needed to be fine-tuned to be as close as possible to those limits. Figure 3.45 shows an example of fine tuning of parameters. In this example, Building Depth parameter is determinant factor since all of the other parameters is fixed to a desired value. When this value is changed by 0.1 meters, rule automatically adds one more floor on top of the building, but gives a warning that the number of floors exceeds the allowed value. Most of the modeling time is allocated to precise tuning of values to conform the regulation.

Buildings within clusters are tied to each other in terms of parameters and attributes. Nature of the written algorithm allows segregation of different clusters in terms of layout shape, but does not allow individual inputs for parameters such as footprint partition, inner setbacks or even façade details. It would be impractical to enable parameters for each cluster or building within a large parcel. There would be a great increase in the number of parameters to be filled in order to model a clustered parcel.

As mentioned previously, batch editing of parameter values with clustered layouts is a time-saver method but it limits the control over the singular items. On the other hand, both alternatives strictly conform to planning regulations. Since, there are functions in the rule file, which check the geometry for violations such as in Figure 3.45, compliance to plan regulations is proved.

Figure 3.45 : Fine-tuning for precise consistency.

One of the most crucial features of PM is reporting. Procedural rules make it possible and easy to describe an urban environment by using density or performance matrix. These matrixes can describe and prescribe different urban interventions. In CE, reports are outputs of predefined calculations in the rules. CE automatically calculate and report required information while generating a model of selected shape. A typical reports segment in CE includes detailed quantitative information about the selected model (Figure 3.46).

Compiled outputs of two alternative models are given in the Table 3.9. In the light of these outputs, quantitative evaluation of two alternatives gets easier. Reports are grouped under headings. Demographic indicators include number of buildings, dwellings and population which gives an information about the capacity characteristics of the area. *Areas* group includes total coverage areas of built environment. Group of *Usage* shows the distribution of land use types within the constructed buildings. *Costs*

& Values summarizes the development costs and retail values which calculated by using average values. Lastly, a simple prediction of the requirements of energy or water as well as domestic waste production of the development is reported.

According to final outputs, 437 buildings are created in the alternative B, while

Reports

Report	N	%	Sum	%	Avg	Min	Max	NaNs
Area, Grass	26	0.00	714.81	0.00	27.49	2.79	85.37	0
Area, Hardscape	26	0.00	1301.28	0.00	50.05	0.26	287.01	0
Construction, Building Cost	11	0.00	7166623.00	0.00	651511.18	498977.00	837363.00	0
Cost, Grass	26	0.00	21444.16	0.00	824.78	83.73	2561.25	0
Cost, Hardscape	26	0.00	78076.89	0.00	3002.96	15.77	17220.83	0
Cost, Tree	2	0.00	400.00	0.00	200.00	200.00	200.00	0
Demographics, Dwelling Units	11	0.00	48.00	0.00	4.36	4.00	5.00	0
Demographics, Population	11	0.00	189.00	0.00	17.18	12.50	22.50	0
Development, Max Floors	1	0.00	6.00	0.00	6.00	6.00	6.00	0
Development, Building Height	11	0.00	40.50	0.00	3.68	3.50	4.50	0
Development, Coverage Real	2	0.00	0.33	0.00	0.17	0.15	0.18	0
Development, Coverage Target	1	0.00	0.33	0.00	0.33	0.33	0.33	0
Development, FAR Real	11	0.00	1.99	0.00	0.18	0.15	0.21	0
Development, FAR Target	1	0.00	2.00	0.00	2.00	2.00	2.00	0
Development, Footprint Real	2	0.00	1001.98	0.00	500.99	443.74	558.24	0
Development, Footprint Target	1	0.00	0.00	0.00	0.00	0.00	0.00	0
Development, GFA Real	11	0.00	5991.98	0.00	544.73	443.74	623.78	0
Development, GFA Target	1	0.00	6036.84	0.00	6036.84	6036.84	6036.84	0
Env.Rep, Domestic Waste(kg/yr)	11	25.00	2600.00	0.44	236.36	200.00	300.00	0
Env.Rep, Electrical Consumption (kWh/yr)	11	25.00	271000.00	46.37	24636.36	16000.00	45000.00	0
Env.Rep, Gas Consumption (m3/yr)	11	25.00	40800.00	6.98	3709.09	3200.00	4000.00	0
Env.Rep, Water Consumption (m3/yr)	11	25.00	270000.00	46.20	24545.45	16000.00	36000.00	0
Env	44	100.00	584400.00	100.00	13281.82	200.00	45000.00	0
GFA, Commercial	2	0.00	1001.98	0.00	500.99	443.74	558.24	0
GFA, Office	4	0.00	2245.51	0.00	561.38	498.98	623.78	0
GFA, Residential	5	0.00	2744.49	0.00	548.90	498.98	623.78	0
Parcel, Scope X	1	0.00	61.19	0.00	61.19	61.19	61.19	0
Parcel, Scope Z	1	0.00	53.42	0.00	53.42	53.42	53.42	0
Parcel, Size	1	0.00	3018.42	0.00	3018.42	3018.42	3018.42	0
Site, Slope (%)	1	0.00	0.00	0.00	0.00	0.00	0.00	0
Total Buildings	2	0.00	4.00	0.00	2.00	2.00	2.00	0
Value, Retail Value	11	0.00	7970000.00	0.00	724545.45	280000.00	2000000.00	0

Figure 3.46 : An example of Reports section in CE.

Alternative A contains 251 buildings. That is one of the main distinctive facts between two designs. Since Alternative B is focused on creating twin buildings on a single parcel, the number of buildings, there is a significant difference on the number of buildings. Dwelling units are calculated with a syntax that use area intervals to define number of dwelling in a floor. According to this presupposition, different usages have different intervals. As in Table 3.10, number of units in the floor is defined by the intervals. For example, a residential usage floor with the size of 300 m^2 will be labeled as having 3 (highly possible) or 4 (rare) units.

Table 3.9 : Reported values of alternative designs.

	Demographics				Areas (m^2)				
	Buildings	Dwelling Units	Population	Density (p/ha.)	Building Coverage	Total Construction	Green Space	Hardscape	Roads & Sidewalks
Alt. A	251	3,812	10,503	290	73,010	361,897	98,199	40,770	78,228
Alt. B	437	3,826	10,628	300	67,353	353,285	90,497	52,916	78,228

Table 3.9 (continued) : Reported values of alternative designs.

	Usage		Estimated Costs & Values		
	Residential Area	Mixed-Use Area	Building Construction (TL)	Open Space Construction (TL)	Total Retail Value (TL)
Alt. A	309,984	51,912	371,917,800	5,513,271	1,277,464,800
Alt. B	302,547	50,738	363,730,700	7,009,023	1,247,209,400

Table 3.9 (continued) : Reported values of alternative designs.

	Estimated Consumption Values			
	Electric Consumption (kWh/year)	Gas Consumption (l/year)	Water Consumption (m^3/year)	Garbage Production (m^3/year)
Alt. A	16.078.000	3.783.400	15.802.000	190.400
Alt. B	17.773.800	3.820.800	16.016.000	192.800

Table 3.10 : Area calculation intervals for determination of number of units.

Building Use		Possibility	
Residential	Mixed-use	High	Low
0 - 179	0 - 74	1	2
180 – 249	75 - 179	2	3
250 - 399	180 - 299	3	4
400 – 699	300 - 499	4	5
700 – 899	500 - 1099	5	6
900 – 1199	1100 +	6	6
1200 +		7	7

As seen in the Table 3.9, number of dwelling sizes are almost equal. Hence, although number of buildings are different, total construction areas of two alternatives are very close. Determination of dwelling units leads to many successive predictions such as population and density. Since the number of dwelling units in a floor is defined, population in that dwelling can be found. Using household size constants such as in Table 3.11, a prediction can be made for individual buildings as well as large urban areas. Population prediction of two alternatives are close to each other. Thus, density calculations are about 300 persons/ha. which is in compliance with the estimation of zoning plan.

Table 3.11 : List of intervals for household size.

Dwelling Size	Average Household Size
0 - 69	2
70 – 109	2.5
110 – 149	3.5
150 – 199	4.5
200 +	5.5

Total coverage area that buildings cover in total is about 70.000 m^2. Total construction areas of both alternatives are also close to each other with slight difference. Yet there are slight differences, an evaluation can be made to show differences of two alternatives. Alternative A uses more coverage area for buildings while Alternative B gives more area to open spaces. Coverage of roads are exactly same in both alternatives.

Even though a small portion of the study area is allocated to mixed-use, the construction areas of these usages are also reported. Since the planning regulation does not define strict limitations for the development of commercial or office uses in this area, those parcels are left as mixed-use function (Figure 3.47, Figure 3.48).

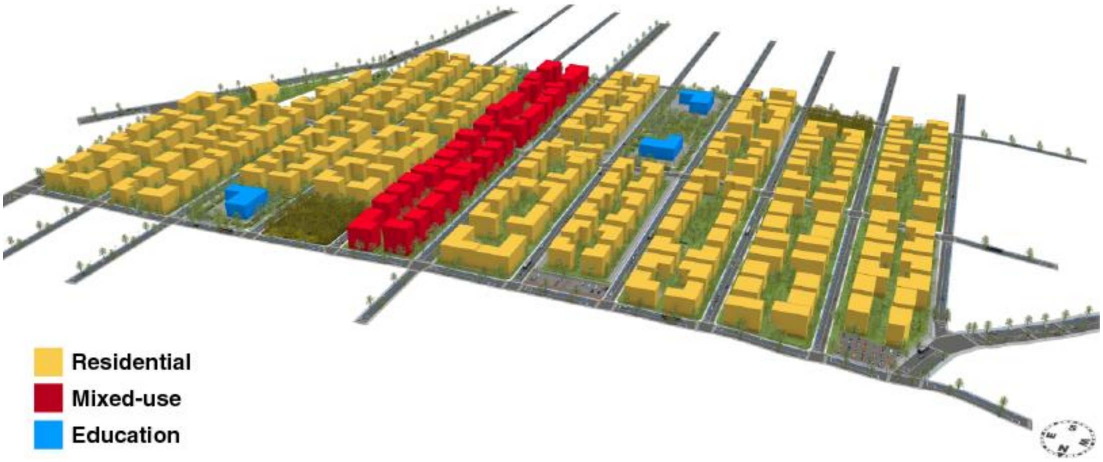


Figure 3.47 : Building use visualization of Alternative A.

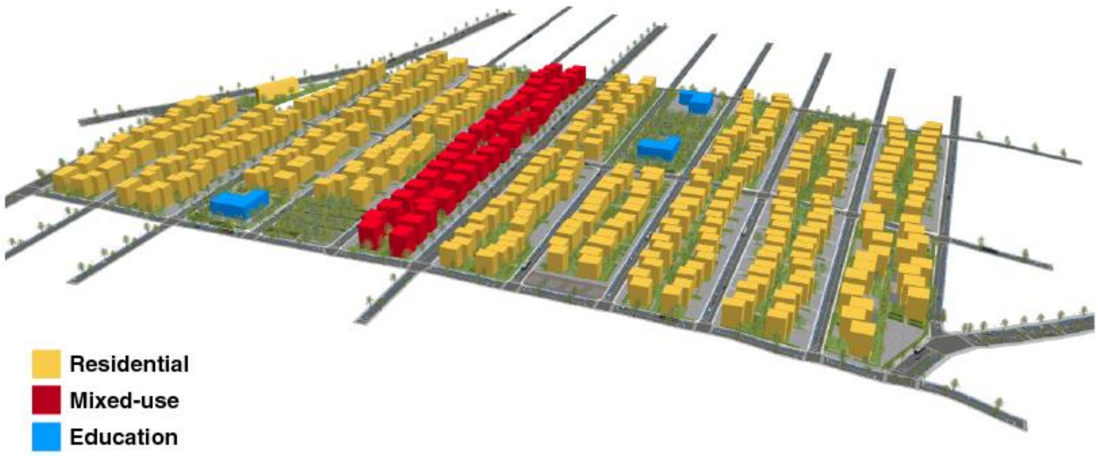


Figure 3.48 : Building use visualization of Alternative B.

By using internal calculations, construction costs and retail values are estimated. Construction costs are estimated by constant values of TL per area as shown in Table 3.12. The values are migrated from official statement on average building unit costs (Ministry of Environment and Urbanisation, 2016). According to the reports, total cost of the development including landscape might require around 370 million TL. On the other hand, retail values are calculated by using average unit values in the neighborhood. The values are compiled from real estate adverts and contemporary values stored by the municipality. Clearly, mixed-use and residential uses have different values. Thus, there are no excessive difference between two final values since they are directly proportionate to total construction areas. While the development designed in Alternative A has an estimated value of 1.28 billion TL, retail value of Alternative B is estimated as 1.25 billion TL. Slight difference between two alternative developments is caused by the difference between total construction areas and the ratio of mixed-use area within the entire development.

Latest group of reports include total consumption estimations of electric, gas and water as well as garbage production estimations. These calculations are crucial in terms of environmental viewpoint. Calculation of total values are based on the average annual consumption values per dwelling. The output values are nearly equal for both alternatives.

Table 3.12 : List of various constant values used in calculations.

Reporting Attribute	Unit	Constant Value
Building Construction Cost (Residential)	TL / m^2	1000
Building Construction Cost (Mixed-Use)	TL / m^2	1350
Building Construction Costs (Schools)	TL / m^2	790
Hardscape Pavers Cost	TL / m^2	60
Average Tree Cost	TL / piece	200
Green Surface Cost Average	TL / m^2	30
Domestic Waste Production	kg/year/dwelling	50
Electric Consumption (Residential)	kWh/dwelling	4000
Electric Consumption (Mixed-use)	kWh/unit	9000
Water Consumption (Residential)	m^3/year/dwelling	4000
Water Consumption (Mixed-use)	m^3/year/unit	6000
Gas Consumption (Residential)	m^3/year/dwelling	1000
Gas Consumption (Mixed-use)	m^3/year/unit	800
Retail Values (Residential)	TL/m^2	3200
Retail Values (Mixed-use)	TL/m^2	5500

3.6.3 Reporting summary

Reporting is one of the most crucial features of CE. Although reports are represented as a final product in this study, they actually work as a feedback mechanism in modeling process. They provide an instant feedback on the actions in the modeling. Any change in the parameters are directly calculated by the CE system and reported. Those changes cause more than one calculation to differ since many of the parameters are connected to each other.

Reporting is considered one of the most crucial aspects of semantic models. If the models would be shared as an online web scene, then reports would also be presented. Users could interrogate the reported values by selecting any of the generated models individually. This feature is available thanks to default web scene parser of CE. However, novel techniques undoubtedly can be developed in order to display compiled values of whole model with the help of scripts.

Particularly in this study, reports have depicted valuable findings. For instance, a distinction between two alternatives can be spotted in terms of building and landscape coverages. Separate buildings in Alternative B cover less area than clustered buildings in Alternative A since separate buildings have smaller units inside whereas clustered buildings have bigger floor areas with bigger building depths. A detailed look in the division between greenspace and hardscape areas within landscape shows that separate buildings in Alternative B triggers creating more hardscape areas. Although buildings cover less area than the other alternative, they are higher in number of buildings. So that, total hardscape area increases since all individual buildings trigger creating a buffer hardscape area around the ground floors.

To sum up, reporting feature carries PM beyond just automatic generation of geometry. Users are able to not only visualize an urban environment but also extend the semantic aspects of the model by generating quantitative reports. These reports are not a final output but also work as instantaneous indicators of design actions. Thus, this feature might be regarded as a part of design tools.

4. CONCLUSION

This chapter consists of three sections concluding the findings of the research. In the first part, general findings about the research will be deliberated. The findings will be synthesized and discussed in the context of hypothesis given in the introduction chapter. In specific, the process of procedural city modeling samples will be recapitulated. Lastly, outputs of the research will be evaluated including possible utilization scenarios and ideas about the further studies.

Second part sums up the means and impediments preventing the code generation process. In particular, the workflow of interpreting legal codes into Computer Generated Architecture (CGA) codes will be deliberated. Additionally, advantages and disadvantages of procedural modeling (PM) and CGA coding will be deliberated. Then, recommendations for better integration of CGA codes with legal codes will be noticed.

Last part covers the general recommendations and findings for urban planning policies. In particular, the implications of spatial planning system in Turkey will be discussed according to research outcomes.

4.1 General Findings

World is rapidly urbanizing. Rapid urbanization requires rapid monitoring and analysis of the cities. Decision makers are increasingly obliged to take proactive actions over rapid changes. In the meantime, new concepts in urban development approaches are transforming the definition of urban planning. Cities all around the globe are striving to be smarter cities which have adapted sustainable approaches that primarily enable envisioning and analyzing the future implications of spatial decisions. Popularity of such movements leads decision makers to examine the consequences of their spatial decisions, quickly.

Therefore, responsible development plans have a crucial role in the future of cities. One of the key concerns of this study is the estimation of future impacts of spatial decisions. It is critical for planning process to evaluate possible formal and quantitative outputs of spatial decisions. On the other hand, use of up-to-date and correct data in spatial analysis is considered as a key element of sustainable planning process. Such plans will require dealing with a considerable amount of data, which can be managed by novel techniques such as PM applications.

This thesis provided an evidence for that 3D-GIS based PM frameworks offer adequate ways to handle, manage and visualize complex data that cities produce both in quantitative and textual mediums. Additionally, outputs of this study show that incorporation with novel techniques eliminate the loss of information in conventional plans. 3D-GIS based PM system in this study offers a dynamic model that can adapt and evolve according to the regulative changes in national urban planning agenda and local plan decision framework. Produced PM system is not designed as a final product itself, and likewise, it does not produce static final products also. It might be considered as a framework that may evolve and adapt according to future changes. This modeling system can dynamically depict the impacts of alternative planning decisions and helps to produce visual predictions of land use policies. Conducted case study have shown that cognitive design computing technologies assist the designer in making design decisions.

There is no hesitation that CityEngine (CE) is transforming and will continue to transform future of urban planning, urban design and even architecture. Yet, it puts forward an interface between these fields. In other words, PM removes the gap between scales, since it enables coding different design solutions for each level of detail. This system, coupled with 3D-GIS, offers adequate management and visualization of data. CE is a viable tool for solving information-related problems in city plans.

In this point, several questions arise about the utilization of such system. CE provides valid communication and data management tools that future planning practices would require. Resulting models can get iteratively more complex. In any level of detail (Figure 4.1), analyses can be conducted in order to test the suitability of GIS-based spatial decisions. This tool can be used for communication with public and for visualizing information. System also can be used in spatial decision-making processes as a tool for providing consensus. Such planning processes would be more practicable practices.

There are different parties that might be interested by the output model such as the one produced in this study. These parties can be listed as urban design firms that are currently commissioned in the area, technical professionals in the local administration, decision-makers in the local administration, managers of non-governmental organizations in local degree and groups from the public. Recent advances in visualization and communication technologies (e.g. virtual reality and augmented reality) can support integration of these models in the means of communication with those parties.

Figure 4.1 : A detailed perspective view from the created models.

The model generated in this study, can be used for visualizing and presenting projects for another part of the city or even for the entire urban macro form. This system can be used for visualizing and presenting projects within the whole city scale. Additionally, procedural modeling ensures variety of level of detail options. This system helps simplifying complicated projects for understanding. It can be used as a decision support tool that helps to identify problems and test planning concepts. On the other hand, PM can also be used to model current situation of urban environments. By integrating models of current development with the model created in this study, analytic and visual evaluations can be conducted. Comparison of current development with new planning alternatives would enhance both quantitative and design aspect of spatial decisions. Additionally, final products of this system can be used as a city inventory tool. Current development of the city can also be modeled in CE, so that this system can store both current form of the city and the future versions of it, in phases.

Consumption reports, that the model produced in the final stage, can help municipal infrastructure service departments. Reports would provide a prediction for the future demands of an area. For instance, in Turkish planning practice, planning departments ask for opinions of these departments on plan revisions. By using such system, a better communication between institutions can be constituted. Since the reports can provide a better insight of the quantitative reflection of the spatial decisions, they enhance the foresight on the demands for urban infrastructure for related departments.

Similarly, cost and values reports facilitate financial programming for developers. Quick exploration of costs and possible values of the development alternatives enables fast feasibility analyses. On the other hand, this system can help in plan revision processes. Planning departments can explore the actual impacts of any plan revision in real-time, by considering the revision in the context of adjacent urban environment.

Further research on this topic would include employment of this tool as an online participation tool. The outputs of this workflow can alternatively be utilized by creating realistic renderings. This system also can be integrated with augmented reality applications in order to create a theoretical framework for an experimental visual urban planning process. The possibilities for the extension of this system to a more useful application are limitless.

This study was aimed to eliminate loss of information the implementation plans hold. Procedural urban modelling has been revealed as an effective tool to foreseen the spatial consequences of any planning policies, and validate the inconsistent and unclear ones. Research has provided evidence that 3D models eliminate the loss of information in three dimensional aspects of the spatial decisions in the plan. Additionally, they enhance the perception of a planned urban space in a more comprehensive way. Study showed that 3D procedural city models improve the sensitive design look in implementation plans. The design aspects of urban plan have been ascertained by the utilization of 3D models.

4.2 Difficulties in Rule-Writing

In this thesis, an approach to simulate an urban model is proposed. This model is aimed to depict the future situation of a study area, which is regulated by the implementation plan and its legal appendix. Although aimed integration of legal planning codes into CGA codes is mostly accomplished, there are impediments preventing the code generation process.

On the other hand, created design alternatives were compelling in terms of geometry. The aim of such over-design was to show that various alternatives can be created using same procedural code and same regulative framework. Thus, two distinctive geometric approaches were designed in order to deliberate the differences easier. Although both alternatives offer different layout structures, they both fulfil the plan regulations. Since there were several validation codes that check the current geometry, each parcel was undoubtedly suitable in terms of legal codes.

There was adequate amount of available data in this study. However, for further visual quality, one should have more detailed data. This model includes GIS based data which the user can make a query to see its full attribute data. Additionally, the model can show the urban environment with more detailed objects. For example, trees, designed landscape areas or existing irregular city objects could have been added to the model. Yet, plan drawing was the only required input for CE to create detailed models in this study. Additionally, height map and ortophoto layers provide the actual slope and topography of the area.

Although PM generally provides a significant advantage in terms of savings in time, there are factors that effects the modeling time in CE. For instance, total modeling time would be higher if the case study area would not include regular parcels. A different case study e.g. in historic city center, would include very irregular-shaped parcels, so that the layout placement and deformation in those parcels would increase the time allocated for manual editing. Plan type is also an effective factor. For instance, a conservation plan would include much more detailed parameters and algorithms as well as more visual interference. Lastly, parcel size is another significant factor. According to the case study experiments, average amount of time for modeling a parcel is inversely proportionate to the size of the parcel. In other words, big parcels require less time since clustered buildings share input parameters and no further editing is required individually for each building. However, small parcels do require individual fine-tuning. Even so, total modeling time in PM is still regarded as so much lower than manual modeling applications.

As a non-expert in CityEngine and CGA coding, rule writing was a compelling process. Thus, there might be so many workaround codes in the produced CGA rules. Written algorithm was designed by considering not only CGA language systematics, but also means of Turkish planning system. Structure and pipeline procedure of the algorithm is aimed to be hierarchically systematic. However, an expert in CGA coding would create much more solid approach. Yet, results of PM process show that such workflows can be utilized in order to adapt Turkish plans into PM systems. Considering that PM is a novel interface for planning systems all around the world, this system can be adapted into various design processes.

There are various findings in the coding process. These findings generally depict the deficiencies and drawbacks of the process. Main algorithm system could be altered in order to create randomized buildings at each model generation. For example, FAR or coverage which are considered as the key factors of regulation, are not the only driving factors within this code. Although the height and total floor areas are determined by these parameters, other factors such as building width and setbacks are other determinants. Slight alterations are possible in the algorithm by restricting the constant-to-parcel values and randomizing the other parameters. For example, instead of providing only a single value, a randomized parameter function can be written with minimum and maximum values such as the regulation define.

The way of clustering would be re-designed. Clustering algorithm is defined as a flat-out approach that define a fixed and solid workflow. In particular, clusters would be created not in foursome groups but also in other numbers. This can be achieved by parametrization of the number with an alternative algorithm. Various selection systems can be defined to define clusters. Yet, on the other hand, an alternative way to handle big parcels would be defined within GIS environment. A similar but more flexible partition system can be defined and automatically employed in the parcels.

On the other hand, building proposals would be modeled in more detail. Although written algorithm could create units and build a dynamic layout, a ragged layout could be coded instead of solid walls. This notion would be promoted by the idea of creation of interiors of buildings. Indeed, this praxis could be beneficial in several issues.

Creation of interiors actually might externalize the inner layout in the outside, eventually can create more dynamic building layouts. It could provide a way better estimation of dwelling units, population and other demands since the system would have been organizing the best interior placement of apartments within buildings.
In this case study, no algorithm for landscape organization is written. Trees are scattered by a randomized code. The code for landscape and hardscape areas is adapted from built-in rulesets. A new design algorithm for landscaping that allows organic design forms could be written. Environmental values are calculated by the limited inputs such as fixed averages, dwelling numbers or area of the concerned unit. More advanced techniques could be defined in order to calculate environmental impacts.
Outputs of case study have shown that CGA is a powerful tool. Various researches have been approved this fact, previously. According to Mandić and Tepavčević (2015), employment of CGA algorithm offers a number of advantages. First, it allows design variations with a single rule database. Second, alternative design solutions are possible. Third, data can be layered to separate elements of city or to separate different design alternatives. Fourth, level of detail is adjustable with a single parameter variation. All of these advantages offer a viable tool for planning.

One of the disadvantages of procedural modelling is that the rules need a certain language. This language is mostly computer-based since in the simplest term they are applied to transform 2D shapes into 3D. In the transformation process, rules are the main procedural algorithms that define the steps of consecutive manipulation. Hence, this language is mostly technical and it should be utilized apart from planning problems.

Although satisfactory results are produced by using current CGA language, there are various limitations as Schwarz and Müller (2015) have also noticed. One of the most crucial findings in this study is that shapes are not contextually in communication with each other. CGA shapes should be able to get information from other shapes, directly. Current form of the language requires artificial workarounds that include manual interventions. For example, a particular parcel should have information about its adjacent parcels for a better harmony in terms of design. Such relation would provide the opportunity to stronger integration with legal codes which occasionally require adaptation of limitations on adjacent parcels.

Another important grammar-based deficiency is that predecessor shapes cannot get information about an ancestor shape if it is not in the same branch of predecessor shape. For example, in the case of this study, clustered buildings lack information about the number of other buildings in the cluster. One cannot produce a code to automate the allocation of total construction area value into generated buildings in several clusters. Since after the geometry is partitioned and layout areas are defined, these layout areas are considered as different branches of the initial shape. In current CGA language, it is not possible for a predecessor shape to get information about other than its own ancestor shapes. Currently, this situation is achieved by manual parameters inputs. One can get any information using the reporting feature, which is possible after the whole scene is generated, not in the model generation process.

All of the abovementioned alterations in the code are addressing a far more complex and integrated code-writing process based on deep investigation. Further research in this topic would address to a more detailed incorporation of regulation on different planning types such as zoning plans, conservation plans or strategic plans. On the other hand, a possible research would experiment outcomes of slight alterations in the code according to the changes in regulation. Indeed, entire pipeline defined in this thesis is also open to alterations and extensions. Since this system is based on textual rules, any slight revision in the regulation can be quickly embedded into the system.

4.3 Policy Recommendations

Urban planning in Turkey has problems in practice, legal system and technical utilization. Legal framework of urban planning and urban development legislation is not stable. Additionally, the problem of illegal processes by-passing necessary procedures is also one of the key issues in contemporary developments. There is an obvious need for reliable frameworks in urbanization and planning policies that are able to produce innovative solutions towards those rapid changes. PM provides significant techniques within this case.

Urban planning practices in Turkey have also technical problems. As the information and communication technologies have been developing rapidly as never before, planning and designing practices should follow these developments. Indeed, Turkish plans consist of drawings and plan notes. However, perceptions of planners, technical staff in authorized intuitions, professionals in related fields and public about these plans are controversial. Since they include technical drawings and terms, the perception of public is in very low levels. On the other hand, ability of professionals to envisage the physical consequences of those plans is also questionable.

To anticipate the consequences of this legal framework is difficult. Since there are many confusing parameters within legal codes, it is difficult to foreseen the outcomes of these 2D plans. However, the plans are not the only case in the debate of perception. Regulative codes are also a part of legal procedures. One of the questionable issues in the spatial planning procedures is the general legal codes which regulate physical development in detail. These regulative codes are generally offer articulating legal clauses instead of a well-structured systematization. General formalization of the regulation includes stochastic rules which mostly do not define the conditions for those alterations. Such formalization brings uncertainty instead of flexibility.

Plan offers strict quantitative regulations for urban plots whereas it lacks enough information about placement and layout regulations. The parameters that existing plans and other codes that plan refers, can be confusing. New parameters and tools are required such as in this study in order to be used in future plans. The conditions for alterations or incentive systems should be defined in a new structure. PM offers a suitable approach for such stochastic rule implementations. Programmed definition of regulative alterations would be re-formularized by using CGA algorithm.

Beylikduzu is one of the fastest developing districts of Istanbul. Assessment of procedural modelling showed that in order to establish a harmonious city, the criteria and limitations of existing policies must be slightly changed. A substantial step would be to decrease the amount of textual statements and to increase formularized parcel-based regulations like zoning codes.

On the other hand, plan offers strict quantitative regulations for urban plots whereas it lacks enough information about placement and layout regulations. Therefore, one of the crucial findings of this research is that implementation plans do not strictly limit the designer, as commonly claimed. For instance, size-based limitations such as maximum sizes of building blocks, type of buildings, color and texture of buildings and many other parameters are mostly subject to design approaches. Although those parameters are partly defined in BPDA, such parameters are mostly related with local characteristics. As shown in this study, planning codes actually leave a significant margin for alternative design approaches based on these parameters.

4.4 General Evaluation and Further Research

This study has conducted a practice on in-hand material. As the main background information, the implementation plan in force is used as legal data. Consequently, CE is proved to have the capability to visualize nearly every possibility that the plan envisions. However, PM tools offer very much more than that. A further research might be to investigate the capabilities of PM to operate the actual urban planning process from scratch to the end. Past researches showed that PM is also capable of simulating urban growth scenarios (Aliaga et al., 2008). Therefore, by using such features, PM would be used as a planning and simulation tool.

In this thesis, a theoretical framework for integration of general parameters of Turkish planning system is presented. Later, a practical implementation of this framework as a semi-automated modeling process is produced. Research provided an evidence for that PM techniques offer viable 3D modeling frameworks for urban areas. It is a fast and cost efficient tool for evaluating the alternative implementation scenarios of plans. 3D-GIS based PM study proved that 3D models increase visual aspects of conventional 2D plans. It has been demonstrated that procedural modelling of the cities can provide significant representations which may address realistic future look of the city. However probable alterations in the framework of urban codes in Turkey can provide more clear predictions for the future look. Such alterations should consider spatial strategy and third dimension of plans.

Although this research has employed a procedural modeling application in order to visualize an implementation plan, there are additional outcomes. Firstly, with the need of new planning conceptions; procedural modeling rules can serve as the actual planning codes. It is proved that conventional planning techniques are insufficient in terms of spatial strategies and creation of livable environments. A comprehensive rule algorithm can be designed in order to see the alternatives within necessary limitations. Secondly, procedural models are seen as an essential tool in the plan-making process. Since PM reports the outputs of the actions immediately, it would be very useful to experiment the alternatives in plan-making processes. Finally, the potential of technology to play a role in the integration of the inherently multidisciplinary planning processes is promising. One must keep in mind that although PM simplifies planning processes, it does not automate entire modeling proess. Obviously, it should be considered as a supportive technology that aid the designer by offering a semi-automatic framework.

Urban planners act with the presupposition that they can imagine the form of possible urban environment that the plan they produced. However, if several plans made for our cities are examined, it will be quite clear that these assumptions are invalid. Planners should get used to utilize novel methods instead of attempting to envisage the environment created by their spatial decisions.

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APPENDICES

Appendix A: CGA Rule written for the study.

Appendix B: Beylikduzu Implementation Plan Notes (English Translation).

Appendix C: Beylikduzu Implementation Plan Notes (Turkish).

Appendix A CGA Rule written for the study.

```
/**
 * File:   Building.cga
 * Author: Cem Demir
**/
version "2015.2"
import Facade : "Support/Building Facades.cga"
import Green_Space : "Support/Greenspace Attributes.cga"
import Zoning : "Support/Zoning.cga"
@Hidden
import envReports : "Support/Environment Reporting.cga"
@Hidden
import MapColor : "Support/ColorMapControl.cga"
@Hidden
import Building_Performance : "Support/Building Performance.cga"
import ParcelBorderRule : "Support/Walls_and_Fences.cga"
import ParkingRule: "Urban_Design/Streets_Parking/Parking_Lot.cga"
@Hidden
import Color : "Support/Colors.cga"
@Hidden
import Text: "Support/Referenced/3D_Text.cga"
@Hidden
attr ImportedFrom = "Parcel"
@Hidden
import
Plant_Distributor_with_LumenRT_Models:"/ESRI.lib/rules/Plants/Plant_Distri
butor.cga"
const assetDirectory = "Zoning_and_Land_Use/"
@Group("DENSITY & ZONING",20) @Order(10)
@Range(0.05, 3)
attr GFAR = Zoning.getZoningData_GFAR
(Zoning.FunctionClassifier(Zoning.PlanFunction))
@Group("DENSITY & ZONING",20) @Order(20)
@Range(0, 2)
attr GFAR_Multiplier = 1
@Group("DENSITY & ZONING",20) @Order(21)
@Range(0, 100000)
attr Manual_GFA_Target = 0
@Group("DENSITY & ZONING") @Order(30)
@Range(0.4, 1)
attr Coverage = Zoning.getZoningData_Coverage(Zoning.PlanFunction)
@Group("DENSITY & ZONING") @Order(40)
@Range(0, 50)
attr Max_Stories = Zoning.getZoningData_MaxStories(Zoning.PlanFunction)
@Group("DENSITY & ZONING") @Order(50)
@Range(3, 100)
attr Height_Max = rint(Max_Stories * Upper_Floor_Height)
@Group("ZONING SETBACKS",30) @Order(8)
@Range(0, 20)
attr Front_Setback = Zoning.getZoningData_SBFront(Zoning.PlanFunction)
@Group("ZONING SETBACKS") @Order(11)
@Range(0, 20)
```

```
attr Left_Setback = Zoning.getZoningData_SBLeft(Zoning.PlanFunction )
@Group("ZONING SETBACKS") @Order(14)
@Range(0, 20)
attr Right_Setback = Zoning.getZoningData_SBRight(Zoning.PlanFunction)
@Group("ZONING SETBACKS") @Order(41)
@Range(0, 20)
attr Rear_Setback = Zoning.getZoningData_SBBack(Zoning.PlanFunction)
@Group("PARCELIZATION",40)
@Order(0)
attr SplitLook = false
@Group("PARCELIZATION",40)
@Order(0)
@Range("By_Size", "Into", "Relative", "Rythm")
attr Split_Method = "By_Size"
@Group("PARCELIZATION",40)
@Order(0)
@Range(-90,90)
attr Rotation = Zoning.getZoningData_SplitRotation(Zoning.PlanFunction)
@Group("PARCELIZATION")
@Order(10)
@Range(20,200)
attr X_Size = Zoning.getZoningData_SplitXSize(Zoning.PlanFunction)
@Group("PARCELIZATION")
@Order(20)
@Range(20,200)
attr Z_Size = Zoning.getZoningData_SplitZSize(Zoning.PlanFunction)
@Group("PARCELIZATION")
@Order(30)
@Range(0,100)
attr X_Offset = 0
@Group("PARCELIZATION")
@Order(40)
@Range(0,100)
attr Z_Offset = 0
@Group("PARCELIZATION")
@Order(51)
@Range(0,100)
attr Min_Lot_Dimension =
Zoning.getZoningData_MinLotDimension(Zoning.PlanFunction)
@Group("PARCELIZATION")
@Order(52)
@Range(0,100)
attr narrownessRatio =
Zoning.getZoningData_narrownessRatio(Zoning.PlanFunction)
@Group("PARCELIZATION")
@Order(52)
@Range(0.01,10)
attr X_1 = Zoning.getZoningData_SplitX1(Zoning.PlanFunction)
@Group("PARCELIZATION")
@Order(52)
@Range(0.01,10)
attr X_2 = Zoning.getZoningData_SplitX2(Zoning.PlanFunction)

@Group("PARCELIZATION")
```

```
@Order(52)
@Range(0.01,10)
attr Z_1 = Zoning.getZoningData_SplitZ1(Zoning.PlanFunction)
@Group("PARCELIZATION")
@Order(52)
@Range(0.01,10)
attr Z_2 = Zoning.getZoningData_SplitZ2(Zoning.PlanFunction)
@Group("BUILDING SETBACKS",50) @Order(1) @Range(0,20)
attr Street_Setback =
Zoning.getZoningData_InnerStreetSetback(Zoning.PlanFunction)
@Group("BUILDING SETBACKS") @Order(2) @Range(0,10)
attr Side_Setback =
Zoning.getZoningData_InnerSideSetback(Zoning.PlanFunction)
@Group("BUILDING SETBACKS") @Order(2) @Range(0,10)
attr Back_Setback =
Zoning.getZoningData_InnerBackSetback(Zoning.PlanFunction)
@Group("BUILDING SETBACKS") @Order(3) @Range("None","2
Stepbacks","Ground Floor Front","Ground Floor 3 Sides","Ground Floor 4
Sides", "2nd Floor","Top
Floor","Increasing","Decreasing","Alternating","Random")
attr Street_Setback_Mode =
Zoning.getZoningData_StreetSetbackMode(Zoning.PlanFunction)
@Group("BUILDING SETBACKS") @Order(4) @Range(0,10)
attr Street_Setback_Distance =
Zoning.getZoningData_SetbackDistance(Zoning.PlanFunction)
@Group("FOOTPRINT PARTITION",61) @Order(1) @Range(0,50)
attr Building_Depth = 13
@Group("FOOTPRINT PARTITION",61) @Order(1)
attr Create_Units = false
@Group("FOOTPRINT PARTITION",61) @Order(2) @Range(0,10)
attr Offset_Distance = 0
@Group("FOOTPRINT PARTITION") @Order(3) @Range(10,50)
attr Unit_Width = 13
@Group("FOOTPRINT PARTITION") @Order(4)
@Range("None","Increasing","Decreasing","Alternating","Random")
attr Offset_Mode = "None"
@Group("FOOTPRINT PARTITION") @Order(5) @Range(0,20)
attr Convexify_Value = 5
@Group("CHECKS",41) @Order(1)
attr ParcelScope_Check = true
@Group("CHECKS",41) @Order(2)
attr LayoutScope_Check = false
@Group("BUILDING HEIGHT") @Order(4) @Range(2.5,5.5)
attr Upper_Floor_Height =
Zoning.getZoningData_UpperFloorHeight(Zoning.PlanFunction)
@Group("BUILDING HEIGHT") @Order(5) @Range(3,6)
attr Ground_Floor_Height =
Zoning.getZoningData_GroundFloorHeight(Zoning.PlanFunction)
@Group("BUILDING HEIGHT") @Order(6) @Range(-4.1,4.1)
attr Foundation_Adjustment = 0
@Group("BUILDING HEIGHT") @Order(7) @Range(-1, 1)
attr Sidewalk_Height_Match = 0
@Group("DISPLAY",80) @Order(12)
attr Zone_Mapping = false
```

```
@Group("DISPLAY") @Order(13)
#@Range("None")
attr Check_Stories = false
#@Group("DISPLAY") @Order(13)
#attr Show_Textures = false
@Group("DISPLAY") @Order(15)
attr Display_Facade_Textures = true
@Group("DISPLAY") @Order(15)
attr Display_GreenSpace_Textures = true
@Group("DISPLAY") @Order(16)
@Range("Thematics Off", "Solid Color","Cluster","Usage","Zoning", "Peak
Runoff/Permeability")
attr Display_Thematics = "Thematics Off"
@Group("DISPLAY") @Order(17)
attr Solid_Color = "#FFFFFF"
@Group("DISPLAY") @Order(4) @Range(0,1)
attr Transparency = 1
@Group("DISPLAY") @Order(10)
attr Story_Edge_Display = false
@Group("GREENSPACE TREATMENT",90) @Order(2)
@Range("Pavers", "Grass","Hardscape & Lawn","Parking","Random")
attr Lot_Buffer_GS = "Random"
@Group("GREENSPACE TREATMENT") @Order(1)
@Range("Pavers", "Grass","Hardscape & Lawn","Parking","Random")
attr General_Setback_GS = "Random"
@Group("GREENSPACE TREATMENT") @Order(3)
@Range("Pavers", "Grass","Hardscape & Lawn","Parking","Random")
attr Split_GS = "Random"
@Group("GREENSPACE TREATMENT") @Order(4)
@Range("Pavers", "Grass","Hardscape & Lawn","Parking","Random")
attr Inner_Lot_GS = "Random"
@Group("GREENSPACE TREATMENT") @Order(5)
@Range("Pavers", "Grass","Hardscape & Lawn","Parking","Random")
attr Small_Shapes_GS = "Random"
@Group("GREENSPACE TREATMENT") @Order(6)
@Range("Pavers", "Grass","Hardscape & Lawn", "Parking","Random")
attr Inner_Setback_GS = "Random"
##################################################################
facadetexturingOn = Display_Facade_Textures
thematicsOn = Display_Thematics != "Thematics Off"
coloringOn = !thematicsOn

thematicColor =
        case Display_Thematics == "Peak Runoff/Permeability": "#FFFFFF"
        case Display_Thematics == "Solid Color":Solid_Color
        case Display_Thematics == "Usage":
                Zoning.getZoningData_Color_Hex(Zoning.PlanFunction)
        case Display_Thematics == "Zoning":
        Color.ColorByUsage(Zoning.FunctionClassifier(Zoning.PlanFunction))
        else: "#FFFFFF"
@Hidden
attr DisableMassDisplay = Zoning.Zoning_Display == "Building & Envelope"
@Hidden
attr Elevation = scope.elevation
```

```
@Hidden
attr Foundation_Height = 0

@Hidden
@StartRule
LotInner -->
GreenSpace

@StartRule
Parcel -->
        case Zoning.getZoningData_AreaType (Zoning.PlanFunction) ==
"Open Space": Green_Space.GreenSpace("openspace",thematicColor)
        case Zoning.getZoningData_AreaType (Zoning.PlanFunction) == "Not
Build": Green_Space.GreenSpace("ForestLike",thematicColor)
        else: ParcelS2
@Hidden
const Parcel_Area = geometry.area
@Hidden
attr Site_Footprint_Target = 0
@Hidden
attr GFA_Target = 0

ParcelS2 -->
        alignScopeToAxes(y)
        report("Site Conditions, Slope (%)", geometry.angle(maxSlope)/90)
        report("Parcel Area (m2)",geometry.area)
        cleanupGeometry(all,1)
        ReportParcel

ReportParcel -->
        case GFAR == 0 && Coverage > 0 :
                report("FAR, Parcel_Area", Parcel_Area)
                report("FAR, Maximum Allowed Floors", Max_Stories)
                #FAR Target
                report("FAR, FAR_Target", Coverage)
                #FA Target
                set (Site_Footprint_Target, Coverage * Parcel_Area)
                report("FAR, FA_Target", Site_Footprint_Target)
                #GFA Target
                set(GFA_Target, Site_Footprint_Target * Max_Stories)
                report("FAR, GFA_Target", GFA_Target)
                #GFAR Target
                set(GFAR,Coverage* Max_Stories)
                report("FAR, GFAR_Target", GFAR_Multiplier * GFAR)
                ParcelVisual
        case GFAR > 0 :
                report("FAR, Parcel_Area", Parcel_Area)
                report("FAR, Maximum Allowed Floors", Max_Stories)
                #FAR Target
                set(Coverage, GFAR/Max_Stories )
                report("FAR, FAR_Target", Coverage)
                #FA Target
                set(Site_Footprint_Target,GFA_Target/Max_Stories )
                report("FAR, FA_Target", Site_Footprint_Target)
```

```
			#GFA Target
			set (GFA_Target, GFAR_Multiplier * GFAR * Parcel_Area)
			report("FAR, GFA_Target", GFA_Target)
			#GFAR Target
			report("FAR, GFAR_Target", GFAR_Multiplier * GFAR)
			ParcelVisual
		else:
			report("FAR, Parcel_Area", Parcel_Area)
			report("FAR, Maximum Allowed Floors", Max_Stories)
			#GFA Target
			set(GFA_Target, Manual_GFA_Target*GFAR_Multiplier)
			report("FAR, GFA_Target", GFA_Target)
			#GFAR Target
			set(GFAR, GFA_Target/Parcel_Area)
			report("FAR, GFAR_Target", GFAR/GFAR_Multiplier)
			#FA Target
			set(Site_Footprint_Target, GFA_Target / Max_Stories)
			report("FAR, FA_Target", Site_Footprint_Target)
			#FAR Target
			report("FAR, FAR_Target", Site_Footprint_Target /
Parcel_Area)
			ParcelVisual

ParcelVisual -->
		case !Zone_Mapping:
			case thematicsOn: color(thematicColor) ParcelBorder
			else: ParcelBorder
		else: color(Zoning.getZoningData_Color_Hex(Zoning.PlanFunction))
		X.
ParcelBorder -->
		case ParcelBorderRule.Create_Protection == true:
			ParcelBorderRule.PlotProtection
			ParcelSetback
		else: ParcelSetback

ParcelSetback -->
		setback(Front_Setback) { front: GreenSpace("GeneralSetback") |
remainder:
			setback(Rear_Setback) { back: GreenSpace("GeneralSetback")
| remainder:
				setback(Left_Setback) { left:
GreenSpace("GeneralSetback") | remainder:
					setback(Right_Setback) { right:
GreenSpace("GeneralSetback") | remainder:
					ParcelSetbackDone1  }}}}

ParcelSetbackDone1 -->
		case geometry.isConcave:
			convexify(3) ParcelSetbackDone
		else: ParcelSetbackDone
ParcelSetbackDone -->
		case ParcelScope_Check == true:
			case _shapeSmall:
				ShapeSmall
```

```
				case _shapeNarrow:
					ShapeSmall
				else:
					BuildableAreaFromSetbacks
		else:
				BuildableAreaFromSetbacks

ShapeSmall -->
		GreenSpace("ShapeSmall")

_shapeSmall = scope.sx < Min_Lot_Dimension || scope.sz <
Min_Lot_Dimension  #|| geometry.area < Smallest_Lot_Size
_shapeNarrow = scope.sx > (scope.sz * narrownessRatio) || scope.sz >
(scope.sx * narrownessRatio)

BuildableAreaFromSetbacks -->
		alignScopeToAxes(y)
		BuildableAreaSubdivideToLots

@Hidden
attr SubdividableArea = 0

BuildableAreaSubdivideToLots -->
		rotateScope(0,Rotation,0)
		set(SubdividableArea, geometry.area)
		Parcelization

Parcelization -->
		case Split_Method == "Into":		Split_IntoX
		case Split_Method == "Relative":	Split_XRelative
		case Split_Method == "Rythm":		Split_XRythm
		else:
		SplitXsize

SplitXsize -->
		split(x)  {
		X_Offset: SplitZsize (split.index+1, split.total) | {
		X_Size : SplitZsize(split.index+1, split.total)}*}
SplitZsize (ix, tx)-->
		split(z) { Z_Offset: LotTypeCheck ("Building",ix,split.index+1, tx,
split.total) |  {Z_Size : LotTypeCheck ("Building",ix, split.index+1, tx,
split.total) }*}

Split_IntoX -->
		split (x) {
				'1/X_1: Split_IntoZ (split.index+1,split.total)}*
Split_IntoZ (ix,tx) -->
		split(z){'1/Z_1 :  LotTypeCheck
("Building",ix,split.index+1,tx,split.total)}*

Split_XRelative -->
		split (x, noAdjust) {'1/X_1: Split_ZRelative(split.index+1,split.total) |
'X_2/10: Split_ZRelative(split.index+1,split.total)}*
Split_ZRelative (ix,tx) -->
```

```
		split (z) {Z_Offset: LotTypeCheck
("Green",ix,split.index+1,tx,split.total) |'Z_2/10 : LotTypeCheck
("Building",ix,split.index+1,tx,split.total) |'Z_1/10 : LotTypeCheck
("Green",ix,split.index+1,tx,split.total) }*

Split_XRythm -->
	split (x, noAdjust) {{ X_1 :
Split_ZRythm("Building",RhythmXClusterizer,split.total) | ~X_2:
GreenSpace} * | X_1 : Split_ZRythm
("Building",RhythmXClusterizer,split.total)}
Split_ZRythm (type,ix,tx) -->
	case type == "Building":
		split (z){{	Z_1 : LotTypeCheck
("Building",ix,RhythmXClusterizer,tx,split.total) |
					~Z_2 : GreenSpace} * |
					Z_1 : LotTypeCheck
("Building",ix,RhythmXClusterizer,tx,split.total)}
	else: GreenSpace

RhythmXClusterizer =
	case split.index == 0: 1
	case split.index > 2 : split.index-1
	case split.index > 4: split.index-2
	case split.index > 6: split.index-3
	case split.index > 8: split.index-4
	case split.index > 10: split.index-5
	case split.index > 12: split.index-6
	case split.index > 14: split.index-7
	else: split.index

const Target_Floor_Area = Coverage * Parcel_Area

@Hidden
attr SplitArea = 0
@Hidden
attr SplitAreaByLot = 0
@Hidden
attr ClusterOffset = 1

LotClassify (ix,iz,tx,tz) -->
	case SplitLook:
		comp(e){all:
			Color.Black
			offset(0.2, border)
			extrude(-0.2)
			X.}
	else:
		case LotBorder(ix,iz,tx,tz):
			ClusterSetter ("Border",ix,iz,tx,tz)
		else:
			#s('1,0,'1)
			ClusterSetter ("Inside",ix,iz,tx,tz)
			####Cluster4x (ix,iz,tx,tz)
			#LotFinal
```

```
ClusterSetter (et,ix,iz,tx,tz) -->
        case ix<=2 && iz<=2: LotFinal(et,"C1",ix,iz,tx,tz)
        case 2 <ix && ix<=4 && iz<=2:        LotFinal(et,"C2",ix,iz,tx,tz)
        case 2<iz && iz<=4 && ix<=2: LotFinal (et,"C3",ix,iz,tx,tz)
        case 3<=iz && iz<=4 && 3<=ix && ix<=4: LotFinal
(et,"C4",ix,iz,tx,tz)
        case 5<=iz && iz<=6 && ix<=2: LotFinal (et,"C5",ix,iz,tx,tz)
        case 3<=ix && ix<=4 && 5<=iz && iz<=6: LotFinal
(et,"C6",ix,iz,tx,tz)
        case 7<=iz && iz<=8 && ix<=2:        LotFinal (et,"C7",ix,iz,tx,tz)
        case 6<iz && iz<9 && 2<ix && ix<5: LotFinal (et,"C8",ix,iz,tx,tz)
        case 5<=ix && ix<=6 && iz<=2:        LotFinal (et,"C9",ix,iz,tx,tz)
        case 7<=ix && ix<=8 && iz<=2:        LotFinal (et,"C10",ix,iz,tx,tz)
        case 3<=iz && iz<=4 && 5<=ix && ix<=6:LotFinal
(et,"C11",ix,iz,tx,tz)
        case 3<=iz && iz<=4 && 7<=ix && ix<=8:LotFinal
(et,"C12",ix,iz,tx,tz)
        case 5<=iz && iz<=6 && 5<=ix && ix<=6:LotFinal
(et,"C13",ix,iz,tx,tz)
        case 5<=iz && iz<=6 && 7<=ix && ix<=8:LotFinal
(et,"C14",ix,iz,tx,tz)
        case 7<=iz && iz<=8 && 5<=ix && ix<=6:LotFinal
(et,"C15",ix,iz,tx,tz)
        case 6<iz && iz<9 && 6<ix && ix<9:   LotFinal (et,"C16",ix,iz,tx,tz)
        else:   LayoutS3

LotBorder(ix,iz,tx,tz) = ix == 1 || ix == tx || iz == 1 || iz == tz

LotTypeCheck (type,ix,iz,tx,tz)-->
        case type == "Green":
                GreenSpace
        case type == "Building":
                LotClassify (ix,iz,tx,tz)
        else:
                NIL

LotFinal (et,cidx,ix,iz,tx,tz) --> // et: edgetype; border or inside / cidx: cluster
index /
                case ParcelScope_Check == true && _shapeSmall:
                        GreenSpace ("ShapeSmall")
                case ParcelScope_Check == true && _shapeNarrow:
                        GreenSpace ("ShapeSmall")
        else:
                case ClusterVisual == true: ClusterColor (cidx)
                else: InsideCommonBoundaryBuffer(et,cidx,ix,iz,tx,tz)

InsideCommonBoundaryBuffer (et,cidx,ix,iz,tx,tz)  -->
        alignScopeToAxes(y)
        convexify()
        t(0,0.01,0)
        setNormals (soft)
        cleanupGeometry(all,0.1)
        Parcel2 (et,cidx,ix,iz,tx,tz)
```

```
Parcel2 (et,cidx,ix,iz,tx,tz)  -->
		set(material.opacity, Transparency)
		alignScopeToAxes(y)
		t(0,Sidewalk_Height_Match,0)
		set(Facade.Display_Facade_Textures, Display_Facade_Textures)
		set(Facade.Display_Thematics, Display_Thematics)
		set(Facade.Solid_Color, Solid_Color)
		set(Facade.Transparency, Transparency)
		set(Facade.Display_Facade_Textures, Display_Facade_Textures)
		set(Facade.Upper_Floor_Height, Upper_Floor_Height)
		set(Facade.Ground_Floor_Height, Ground_Floor_Height)
		set(Facade.DisableMassDisplay, DisableMassDisplay)
		#
		set(Green_Space.Display_GreenSpace_Textures,
Display_GreenSpace_Textures)
		set(Green_Space.Display_Thematics, Display_Thematics)
		set(Green_Space.Solid_Color, Solid_Color)
		set(Green_Space.Transparency, Transparency)
		#
		set(Facade.Photovoltaic_Roof.Display_Textures,
Display_Facade_Textures)
		set(Facade.Photovoltaic_Roof.Display_Thematics, Display_Thematics)
		set(Facade.Photovoltaic_Roof.Solid_Color, Solid_Color)
		set(Facade.Photovoltaic_Roof.Transparency, Transparency)
		set(Facade.Photovoltaic_Roof.Level_of_Detail,
Facade.Level_of_Detail)
		#
		ParcelStep2(et,cidx,ix,iz,tx,tz)

ParcelStep2 (et,cidx,ix,iz,tx,tz)  -->
		case Zoning.Zoning_Display == "Building":
			BuildingAndYards (et,cidx,ix,iz,tx,tz)
		case Zoning.Zoning_Display == "Envelope":

		Zoning.ZoningEnvelope(Front_Setback,Right_Setback,Left_Setback,Ba
ck_Setback,Height_Max)
		else:
			BuildingAndYards  (et,cidx,ix,iz,tx,tz)

		Zoning.ZoningEnvelope(Front_Setback,Right_Setback,Left_Setback,Ba
ck_Setback,Height_Max)

BuildingAndYards  (et,cidx,ix,iz,tx,tz) -->
		roofShed(0)
		SetbackStreet (et,cidx,ix,iz,tx,tz)

SetbackStreet (et,cidx,ix,iz,tx,tz)  -->
		setback(Street_Setback) {front: GreenSpace("InnerSetback") |
remainder :
			setback(Back_Setback) {back: GreenSpace("InnerSetback") |
remainder :
				setback(Side_Setback) {left:
GreenSpace("InnerSetback") | remainder :
```

```
                                        setback(Side_Setback) {right:
GreenSpace("InnerSetback") | remainder :
                                        InnerRect (et,cidx,ix,iz,tx,tz) }}}}

offsetDistance = case Offset_Mode == "None": 0 else: Offset_Distance

mainWingWidth =
          case Street_Setback_Mode == "None": Building_Depth +
offsetDistance
          else:    Building_Depth + Street_Setback_Distance + offsetDistance

getFloorHeight(idx) =
          case idx == 0: Ground_Floor_Height
          else: Upper_Floor_Height

@Hidden
attr currentBuildableAreaIndex = 1

ConstructionArea (et,cidx,ix,iz,tx,tz)  -->
          case geometry.nEdges <= 6:
                    convexify(Convexify_Value)
                    alignScopeToAxes(y)
                    ClusterIndexing (et,cidx,ix,iz)
          else:
                    GreenSpace("InsideLot")

clusterIndexNo1(ix,iz) =          ix==1 && iz==1+0 ||ix==1 && iz==1+2 ||
ix==1 && iz==1+4 ||ix==1 && iz==1+6 ||ix==1 && iz==1+8 ||ix==1 &&
iz==1+10 ||ix==1+2 && iz==1+0 || ix==1+2 && iz==1+2 ||ix==1+2 &&
iz==1+4 ||ix==1+2 && iz==1+6 ||ix==1+2 && iz==1+8 ||ix==1+2 &&
iz==1+10 ||ix==1+4 && iz==1+0 ||ix==1+4 && iz==1+2 ||ix==1+4 &&
iz==1+4 ||ix==1+4 && iz==1+6 ||ix==1+4 && iz==1+8 ||ix==1+4 &&
iz==1+10 ||
ix==1+6 && iz==1+0 ||ix==1+6 && iz==1+2 ||ix==1+6 && iz==1+4 ||
ix==1+6 && iz==1+6 ||ix==1+6 && iz==1+8 ||ix==1+2 && iz==1+2
||ix==1+4 && iz==1+4 || ix==1+6 && iz==1+6 ||ix==1+8 && iz==1+8 ||
ix==1+10 && iz==1+10


clusterIndexNo2(ix,iz) = ix==1 && iz==1+1 ||ix==1 && iz==1+3 ||ix==1 &&
iz==1+5 ||ix==1 && iz==1+7 ||ix==1 && iz==1+9 ||ix==1 && iz==1+11 ||
ix==1+2 && iz==1+1 || ix==1+2 && iz==1+3 ||ix==1+2 && iz==1+5 ||
ix==1+2 && iz==1+7 ||ix==1+2 && iz==1+9 ||ix==1+2 && iz==1+11 ||
ix==1+4 && iz==1+1 ||ix==1+4 && iz==1+3 ||ix==1+4 && iz==1+5 ||
ix==1+4 && iz==1+7 || ix==1+4 && iz==1+9 || ix==1+4 && iz==1+11 ||
ix==1+6 && iz==1+1 || ix==1+6 && iz==1+3 || ix==1+6 && iz==1+5 ||
ix==1+6 && iz==1+7 ||ix==1+6 && iz==1+9 ||ix==1+6 && iz==1+11

clusterIndexNo3(ix,iz) =          ix==1+1 && iz==1 ||ix==1+1 && iz==1+2 ||
ix==1+1 && iz==1+4 ||ix==1+1 && iz==1+6 ||ix==1+1 && iz==1+8 ||
ix==1+1 && iz==1+10 ||ix==1+3 && iz==1 || ix==1+3 && iz==1+2 || ix==1+3
&& iz==1+4 || ix==1+3 && iz==1+6 || ix==1+3 && iz==1+8 || ix==1+3 &&
iz==1+10 || ix==1+5 && iz==1 || ix==1+5 && iz==1+2 || ix==1+5 &&
iz==1+4 || ix==1+5 && iz==1+6 || ix==1+5 && iz==1+8 || ix==1+5 &&
```

```
iz==1+10 || ix==1+7 && iz==1+0 || ix==1+7 && iz==1+2 || ix==1+7 &&
iz==1+4 || ix==1+7 && iz==1+6 || ix==1+7 && iz==1+8 || ix==1+7 &&
iz==1+10


clusterIndexNo4(ix,iz) = ix==1+1 && iz==1+1 || ix==1+1 && iz==1+3 ||
ix==1+1 && iz==1+5 || ix==1+1 && iz==1+7 || ix==1+1 && iz==1+9 ||
ix==1+1 && iz==1+11 || ix==1+3 && iz==1+1 || ix==1+3 && iz==1+3 ||
ix==1+3 && iz==1+5 || ix==1+3 && iz==1+7 || ix==1+3 && iz==1+9 ||
ix==1+3 && iz==1+11 || ix==1+5 && iz==1+1 || ix==1+5 && iz==1+3 ||
ix==1+5 && iz==1+5 || ix==1+5 && iz==1+7 || ix==1+5 && iz==1+9 ||
ix==1+5 && iz==1+11 || ix==1+7 && iz==1+1 || ix==1+7 && iz==1+3 ||
ix==1+7 && iz==1+5 || ix==1+7 && iz==1+7 || ix==1+7 && iz==1+9 ||
ix==1+7 && iz==1+11

@Hidden
attr clusterOffset = 0

ClusterColor (cidx) -->
        case ClusterVisual == true:
                Text.PrintLines(cidx, 1)
                Color.Cluster(cidx)
        else: NIL

ClusterIndexSetter (id,cidx) -->
        case clusterOffset == 90:
                case id == 1:  ClusterRule (4,cidx)
                case id == 2:  ClusterRule (1,cidx)
                case id == 3:  ClusterRule (3,cidx)
                else: ClusterRule (id,cidx)
        case clusterOffset == 180:
                case id == 1: ClusterRule (3,cidx)
                case id == 2: ClusterRule (4,cidx)
                case id == 3: ClusterRule (2,cidx)
                else: ClusterRule (1,cidx)
        case clusterOffset == 270:
                case id == 1: ClusterRule (2,cidx)
                case id == 2: ClusterRule (3,cidx)
                case id == 3: ClusterRule (1,cidx)
                else: ClusterRule (4,cidx)
        else:
                case id == 1: ClusterRule (1,cidx)
                case id == 2: ClusterRule (2,cidx)
                case id == 3: ClusterRule (3,cidx)
                else: ClusterRule (4,cidx)

ClusterIndexing (et,cidx,ix,iz)-->
case clusterIndexNo1(ix,iz):  ClusterIndexSetterS1 (1,cidx)
case clusterIndexNo2(ix,iz):  ClusterIndexSetterS1 (2,cidx)
case clusterIndexNo3(ix,iz):  ClusterIndexSetterS1(3,cidx)
case clusterIndexNo4(ix,iz):  ClusterIndexSetterS1 (4,cidx)
else: NIL

ClusterIndexSetterS1 (id,cidx)-->
```

```
case cidx == "C1": set(clusterOffset, C1_Reset)  ClusterIndexSetter (id,cidx)
case cidx == "C2": set(clusterOffset, C2_Reset)  ClusterIndexSetter (id,cidx)
case cidx == "C3": set(clusterOffset, C3_Reset)  ClusterIndexSetter (id,cidx)
case cidx == "C4": set(clusterOffset, C4_Reset)  ClusterIndexSetter (id,cidx)
case cidx == "C5": set(clusterOffset, C5_Reset)  ClusterIndexSetter (id,cidx)
case cidx == "C6": set(clusterOffset, C6_Reset)  ClusterIndexSetter (id,cidx)
case cidx == "C7": set(clusterOffset, C7_Reset)  ClusterIndexSetter (id,cidx)
case cidx == "C8": set(clusterOffset, C8_Reset)  ClusterIndexSetter (id,cidx)
case cidx == "C9": set(clusterOffset, C9_Reset)  ClusterIndexSetter (id,cidx)
case cidx == "C10": set(clusterOffset, C10_Reset)  ClusterIndexSetter (id,cidx)
else: ClusterIndexSetter (id,cidx)

@Group("CLUSTERING",59) @Order(10)
attr ClusterVisual = false
@Group("CLUSTERING",59) @Order(13) @Range(0,90,180,270)
attr C1_Rotation = 0
@Group("CLUSTERING",59) @Order(12) @Range(0,90,180,270)
attr C1_Reset = 0
@Group("CLUSTERING",59) @Order(11) @Range(0,4)
attr C1_Buildings = 1
@Group("CLUSTERING",59) @Order(14) @Range("U-Shaped","All
Front","L-Shaped","U-Shaped","O-Shaped","Total Areas","Not Build","Only
One","All-O","All-U","All-L")
attr C1_Type = MapColor.selectbycolor
@Group("CLUSTERING",59) @Order(23) @Range(0,90,180,270)
attr C2_Rotation = 0
@Group("CLUSTERING",59) @Order(22) @Range(0,90,180,270)
attr C2_Reset = 0
@Group("CLUSTERING",59) @Order(21) @Range(0,4)
attr C2_Buildings = 0
@Group("CLUSTERING",59) @Order(24) @Range("U-Shaped","All
Front","L-Shaped","U-Shaped","O-Shaped","Total Areas","Not Build","Only
One","All-O","All-U","All-L")
attr C2_Type = "Not Build"
@Group("CLUSTERING",59) @Order(33) @Range(0,90,180,270)
attr C3_Rotation = 0
@Group("CLUSTERING",59) @Order(32) @Range(0,90,180,270)
attr C3_Reset = 0
@Group("CLUSTERING",59) @Order(31) @Range(0,4)
attr C3_Buildings = 0
@Group("CLUSTERING",59) @Order(34) @Range("U-Shaped","All
Front","L-Shaped","U-Shaped","O-Shaped","Total Areas","Not Build","Only
One","All-O","All-U","All-L")
attr C3_Type = "Not Build"
@Group("CLUSTERING",59) @Order(43) @Range(0,90,180,270)
attr C4_Rotation = 0
@Group("CLUSTERING",59) @Order(42) @Range(0,90,180,270)
attr C4_Reset = 0
@Group("CLUSTERING",59) @Order(41) @Range(0,4)
attr C4_Buildings = 0
@Group("CLUSTERING",59) @Order(44) @Range("U-Shaped","All
Front","L-Shaped","U-Shaped","O-Shaped","Total Areas","Not Build","Only
One","All-O","All-U","All-L")
attr C4_Type = "Not Build"
```

```
@Group("CLUSTERING",59) @Order(53) @Range(0,90,180,270)
attr C5_Rotation = 0
@Group("CLUSTERING",59) @Order(52) @Range(0,90,180,270)
attr C5_Reset = 0
@Group("CLUSTERING",59) @Order(51) @Range(0,4)
attr C5_Buildings = 0
@Group("CLUSTERING",59) @Order(54) @Range("U-Shaped","All
Front","L-Shaped","U-Shaped","O-Shaped","Total Areas","Not Build","Only
One","All-O","All-U","All-L")
attr C5_Type = "Not Build"
@Group("CLUSTERING",59) @Order(63) @Range(0,90,180,270)
attr C6_Rotation = 0
@Group("CLUSTERING",59) @Order(62) @Range(0,90,180,270)
attr C6_Reset = 0
@Group("CLUSTERING",59) @Order(61) @Range(0,4)
attr C6_Buildings = 0
@Group("CLUSTERING",59) @Order(64) @Range("U-Shaped","All
Front","L-Shaped","U-Shaped","O-Shaped","Total Areas","Not Build","Only
One","All-O","All-U","All-L")
attr C6_Type = "Not Build"
@Group("CLUSTERING",59) @Order(73) @Range(0,90,180,270)
attr C7_Rotation = 0
@Group("CLUSTERING",59) @Order(72) @Range(0,90,180,270)
attr C7_Reset = 0
@Group("CLUSTERING",59) @Order(71) @Range(0,4)
attr C7_Buildings = 0
@Group("CLUSTERING",59) @Order(74) @Range("U-Shaped","All
Front","L-Shaped","U-Shaped","O-Shaped","Total Areas","Not Build","Only
One","All-O","All-U","All-L")
attr C7_Type = "Not Build"
@Group("CLUSTERING",59) @Order(83) @Range(0,90,180,270)
attr C8_Rotation = 0
@Group("CLUSTERING",59) @Order(82) @Range(0,90,180,270)
attr C8_Reset = 0
@Group("CLUSTERING",59) @Order(81) @Range(0,4)
attr C8_Buildings = 0
@Group("CLUSTERING",59) @Order(84) @Range("U-Shaped","All
Front","L-Shaped","U-Shaped","O-Shaped","Total Areas","Not Build","Only
One","All-O","All-U","All-L")
attr C8_Type = "Not Build"
@Group("CLUSTERING",59) @Order(93) @Range(0,90,180,270)
attr C9_Rotation = 0
@Group("CLUSTERING",59) @Order(92) @Range(0,90,180,270)
attr C9_Reset = 0
@Group("CLUSTERING",59) @Order(91) @Range(0,4)
attr C9_Buildings = 0
@Group("CLUSTERING",59) @Order(94) @Range("U-Shaped","All
Front","L-Shaped","U-Shaped","O-Shaped","Total Areas","Not Build","Only
One","All-O","All-U","All-L")
attr C9_Type = "Not Build"
@Group("CLUSTERING",59) @Order(103) @Range(0,90,180,270)
attr C10_Rotation = 0
@Group("CLUSTERING",59) @Order(102) @Range(0,90,180,270)
attr C10_Reset = 0
```

```
@Group("CLUSTERING",59) @Order(101) @Range(0,4)
attr C10_Buildings = 0
@Group("CLUSTERING",59) @Order(104) @Range("U-Shaped","All
Front","L-Shaped","U-Shaped","O-Shaped","Total Areas","Not Build","Only
One","All-O","All-U","All-L")
attr C10_Type = "Not Build"
@Group("CLUSTERING",59) @Order(113) @Range(0,90,180,270)
attr C11_Rotation = 0
@Group("CLUSTERING",59) @Order(112) @Range(0,90,180,270)
attr C11_Reset = 0
@Group("CLUSTERING",59) @Order(114) @Range("U-Shaped","All
Front","L-Shaped","U-Shaped","O-Shaped","Total Areas","Not Build","Only
One","All-O","All-U","All-L")
attr C11_Type = "Not Build"
@Group("CLUSTERING",59) @Order(111) @Range(0,4)
attr C11_Buildings = 0

@Hidden
attr ClusterRotation = 0

ClusterRule (id,cidx) -->
        case cidx=="C1":
                case C1_Type == "U-Shaped": set(ClusterRotation,
C1_Rotation) ClusterUShape (id)
                case C1_Type == "All Front": set(ClusterRotation,
C1_Rotation) ClusterIShape(id)
                case C1_Type =="L-Shaped": set(ClusterRotation,
C1_Rotation) ClusterLShape((id))
                case C1_Type =="O-Shaped": set(ClusterRotation,
C1_Rotation) ClusterOShape(id)
                case C1_Type =="All-O": set(ClusterRotation, C1_Rotation)
ClusterAllO
                case C1_Type =="All-U": set(ClusterRotation, C1_Rotation)
ClusterAllU
                case C1_Type =="All-L": set(ClusterRotation, C1_Rotation)
ClusterAllL
                case C1_Type =="Not Build": GreenSpace ("InsideLot")
                case C1_Type == "Only One": set(ClusterRotation,
C1_Rotation) ClusterOnlyOne(id)
                else: set(ClusterRotation, C1_Rotation)Layout    //"Total
Areas"
        case cidx=="C2":
                case C2_Type == "U-Shaped": set(ClusterRotation,
C2_Rotation) ClusterUShape(id)
                case C2_Type == "All Front": set(ClusterRotation,
C2_Rotation) ClusterIShape(id)
                case C2_Type =="L-Shaped": set(ClusterRotation,
C2_Rotation) ClusterLShape(id)
                case C2_Type =="O-Shaped": set(ClusterRotation,
C2_Rotation) ClusterOShape(id)
                case C2_Type == "Only One": set(ClusterRotation,
C2_Rotation) ClusterOnlyOne(id)
                case C2_Type =="Not Build": GreenSpace ("InsideLot")
```

```
                case C2_Type =="All-O": set(ClusterRotation, C2_Rotation) ClusterAllO
                case C2_Type =="All-U": set(ClusterRotation, C2_Rotation) ClusterAllU
                case C2_Type =="All-L": set(ClusterRotation, C2_Rotation) ClusterAllL
                else: set(ClusterRotation, C2_Rotation) Layout
        //"Total Areas"
        case cidx=="C3":
                case C3_Type == "U-Shaped": set(ClusterRotation, C3_Rotation) ClusterUShape(id)
                case C3_Type == "All Front": set(ClusterRotation, C3_Rotation) ClusterIShape(id)
                case C3_Type =="L-Shaped": set(ClusterRotation, C3_Rotation) ClusterLShape(id)
                case C3_Type =="O-Shaped": set(ClusterRotation, C3_Rotation) ClusterOShape(id)
                case C3_Type == "Only One": set(ClusterRotation, C3_Rotation) ClusterOnlyOne(id)
                case C3_Type =="Not Build": GreenSpace ("InsideLot")
                case C3_Type =="All-O": set(ClusterRotation, C3_Rotation) ClusterAllO
                case C3_Type =="All-U": set(ClusterRotation, C3_Rotation) ClusterAllU
                case C3_Type =="All-L": set(ClusterRotation, C3_Rotation) ClusterAllL
                else: set(ClusterRotation, C3_Rotation) Layout   //"Total Areas"
        case cidx=="C4":
                case C4_Type == "U-Shaped": set(ClusterRotation, C4_Rotation) ClusterUShape(id)
                case C4_Type == "All Front": set(ClusterRotation, C4_Rotation) ClusterIShape(id)
                case C4_Type =="L-Shaped": set(ClusterRotation, C4_Rotation) ClusterLShape(id)
                case C4_Type =="O-Shaped": set(ClusterRotation, C4_Rotation) ClusterOShape(id)
                case C4_Type == "Only One": set(ClusterRotation, C4_Rotation) ClusterOnlyOne(id)
                case C4_Type =="Not Build": GreenSpace ("InsideLot")
                case C4_Type =="All-O": set(ClusterRotation, C4_Rotation) ClusterAllO
                case C4_Type =="All-U": set(ClusterRotation, C4_Rotation) ClusterAllU
                case C4_Type =="All-L": set(ClusterRotation, C4_Rotation) ClusterAllL
                else: set(ClusterRotation, C4_Rotation) Layout
        //"Total Areas"
        case cidx=="C5":
                case C5_Type == "U-Shaped": set(ClusterRotation, C5_Rotation) ClusterUShape(id)
                case C5_Type == "All Front": set(ClusterRotation, C5_Rotation) ClusterIShape(id)
```

```
                case C5_Type =="L-Shaped": set(ClusterRotation,
C5_Rotation) ClusterLShape(id)
                case C5_Type =="O-Shaped": set(ClusterRotation,
C5_Rotation) ClusterOShape(id)
                case C5_Type =="Not Build": GreenSpace ("InsideLot")
                case C5_Type =="All-O": set(ClusterRotation, C5_Rotation)
ClusterAllO
                case C5_Type =="All-U": set(ClusterRotation, C5_Rotation)
ClusterAllU
                case C5_Type =="All-L": set(ClusterRotation, C5_Rotation)
ClusterAllL
                else: set(ClusterRotation, C5_Rotation) Layout
        //"Total Areas"
        case cidx=="C6":
                case C6_Type == "U-Shaped": set(ClusterRotation,
C6_Rotation) ClusterUShape(id)
                case C6_Type == "All Front": set(ClusterRotation,
C6_Rotation) ClusterIShape(id)
                case C6_Type =="L-Shaped": set(ClusterRotation,
C6_Rotation) ClusterLShape(id)
                case C6_Type =="O-Shaped": set(ClusterRotation,
C6_Rotation) ClusterOShape(id)
                case C6_Type =="Not Build": GreenSpace ("InsideLot")
                case C6_Type =="All-O": set(ClusterRotation, C6_Rotation)
ClusterAllO
                case C6_Type =="All-U": set(ClusterRotation, C6_Rotation)
ClusterAllU
                case C6_Type =="All-L": set(ClusterRotation, C6_Rotation)
ClusterAllL
                else: set(ClusterRotation, C6_Rotation) Layout   //"Total
Areas"
        case cidx=="C7":
                case C7_Type == "U-Shaped": set(ClusterRotation,
C7_Rotation) ClusterUShape(id)
                case C7_Type == "All Front": set(ClusterRotation,
C7_Rotation) ClusterIShape(id)
                case C7_Type =="L-Shaped": set(ClusterRotation,
C7_Rotation) ClusterLShape(id)
                case C7_Type =="O-Shaped": set(ClusterRotation,
C7_Rotation) ClusterOShape(id)
                case C7_Type =="Not Build": GreenSpace ("InsideLot")
                case C7_Type =="All-O": set(ClusterRotation, C7_Rotation)
ClusterAllO
                case C7_Type =="All-U": set(ClusterRotation, C7_Rotation)
ClusterAllU
                case C7_Type =="All-L": set(ClusterRotation, C7_Rotation)
ClusterAllL
                else: set(ClusterRotation, C7_Rotation) Layout
        //"Total Areas"
        case cidx=="C8":
                case C8_Type == "U-Shaped": set(ClusterRotation,
C8_Rotation) ClusterUShape(id)
                case C8_Type == "All Front": set(ClusterRotation,
C8_Rotation) ClusterIShape(id)
```

```
                    case C8_Type =="L-Shaped": set(ClusterRotation,
C8_Rotation) ClusterLShape(id)
                    case C8_Type =="O-Shaped": set(ClusterRotation,
C8_Rotation) ClusterOShape(id)
                    case C8_Type =="Not Build": GreenSpace ("InsideLot")
                    case C8_Type =="All-O": set(ClusterRotation, C8_Rotation)
ClusterAllO
                    case C8_Type =="All-U": set(ClusterRotation, C8_Rotation)
ClusterAllU
                    case C8_Type =="All-L": set(ClusterRotation, C8_Rotation)
ClusterAllL
                    else: set(ClusterRotation, C8_Rotation) Layout
          //"Total Areas"
          case cidx=="C9":
                    case C9_Type == "U-Shaped": set(ClusterRotation,
C9_Rotation) ClusterUShape(id)
                    case C9_Type == "All Front": set(ClusterRotation,
C9_Rotation) ClusterIShape(id)
                    case C9_Type =="L-Shaped": set(ClusterRotation,
C9_Rotation) ClusterLShape(id)
                    case C9_Type =="O-Shaped": set(ClusterRotation,
C9_Rotation) ClusterOShape(id)
                    case C9_Type =="Not Build": GreenSpace ("InsideLot")
                    case C9_Type =="All-O": set(ClusterRotation, C9_Rotation)
ClusterAllO
                    case C9_Type =="All-U": set(ClusterRotation, C9_Rotation)
ClusterAllU
                    case C9_Type =="All-L": set(ClusterRotation, C9_Rotation)
ClusterAllL
                    else: set(ClusterRotation, C9_Rotation) Layout
          //"Total Areas"
          case cidx=="C10":
                    case C10_Type == "U-Shaped": set(ClusterRotation,
C10_Rotation) ClusterUShape(id)
                    case C10_Type == "All Front": set(ClusterRotation,
C10_Rotation) ClusterIShape(id)
                    case C10_Type =="L-Shaped": set(ClusterRotation,
C10_Rotation) ClusterLShape(id)
                    case C10_Type =="O-Shaped": set(ClusterRotation,
C10_Rotation) ClusterOShape(id)
                    case C10_Type =="Not Build": GreenSpace ("InsideLot")
                    case C10_Type =="All-O": set(ClusterRotation, C10_Rotation)
ClusterAllO
                    case C10_Type =="All-U": set(ClusterRotation, C10_Rotation)
ClusterAllU
                    case C10_Type =="All-L": set(ClusterRotation, C10_Rotation)
ClusterAllL
                    else: set(ClusterRotation, C10_Rotation) Layout
          //"Total Areas"
          case cidx=="C11":
                    case C11_Type == "U-Shaped": set(ClusterRotation,
C11_Rotation) ClusterUShape(id)
                    case C11_Type == "All Front": set(ClusterRotation,
C11_Rotation) ClusterIShape(id)
```

```
			case C11_Type =="L-Shaped": set(ClusterRotation, C11_Rotation) ClusterLShape(id)
			case C11_Type =="O-Shaped": set(ClusterRotation, C11_Rotation) ClusterOShape(id)
			case C11_Type =="Not Build": GreenSpace ("InsideLot")
			case C11_Type =="All-O": set(ClusterRotation, C11_Rotation) ClusterAllO
			case C11_Type =="All-U": set(ClusterRotation, C11_Rotation) ClusterAllU
			case C11_Type =="All-L": set(ClusterRotation, C11_Rotation) ClusterAllL
			else: set(ClusterRotation, C11_Rotation) Layout
		//"Total Areas"
		else: Layout

ClusterOnlyOne(id) -->
		case id==1:
			Layout
		else: GreenSpace ("InsideLot")

ClusterUShape(id) -->
		case id==1: rotateScope(0, ClusterRotation-90, 0) LShape
		case id==2: rotateScope(0, ClusterRotation, 0) LShape
		case id==3: rotateScope(0, ClusterRotation+180, 0) IShape
		case id==4: rotateScope(0, ClusterRotation+0, 0) IShape
		else:IShape
ClusterLShape (id) -->
		case id==1: rotateScope(0, ClusterRotation-90, 0) LShape
		case id==2: rotateScope(0, ClusterRotation-90, 0) IShape
		case id==3: rotateScope(0, ClusterRotation+180, 0) IShape
		case id==4: GreenSpace ("InsideLot")
		else:IShape
ClusterOShape (id) -->
		case id==1: rotateScope(0, ClusterRotation-90, 0) LShape
		case id==2: rotateScope(0, ClusterRotation, 0) LShape
		case id==3: rotateScope(0, ClusterRotation+180, 0) LShape
		case id==4: rotateScope(0, ClusterRotation+90, 0) LShape
		else:OShape
ClusterIShape(id)-->
			rotateScope(0, ClusterRotation, 0)
			IShape

ClusterAllO --> rotateScope(0, ClusterRotation, 0) OShape
ClusterAllU --> rotateScope(0, ClusterRotation, 0) UShape
ClusterAllL --> rotateScope(0, ClusterRotation, 0) LShape

IShape --> setback(mainWingWidth) { front : Layout | remainder : GreenSpace("InsideLot") }

LShape --> shapeL(Building_Depth,mainWingWidth) { shape : Layout  | remainder : GreenSpace("InsideLot") }
OShape -->
		shapeO(mainWingWidth,Building_Depth,mainWingWidth,Building_Depth) { shape : Layout | remainder : GreenSpace("InsideLot") }
```

```
UShape -->
	shapeO(mainWingWidth,Building_Depth,0,Building_Depth) { shape :
Layout| remainder : GreenSpace("InsideLot") }

InnerRect (et,cidx,ix,iz,tx,tz)  -->
	#alignScopeToAxes(y)
	convexify(Convexify_Value)
	#innerRect
	ConstructionArea (et,cidx,ix,iz,tx,tz)
	#t(0,1,0)
	#t(1,0,1)
	#s('1,0,'1)

@Hidden
attr LayoutSlope = 0
@Hidden
attr LayoutScopeSize = 0

TotalBuildings = C1_Buildings+C2_Buildings+C3_Buildings+C4_Buildings
+C5_Buildings+C6_Buildings+C7_Buildings+C8_Buildings+C9_Buildings+C1
0_Buildings+C11_Buildings
BuildingGFA = (GFA_Target/TotalBuildings

Layout  -->
case LayoutScope_Check == true:
	case _LayoutShapeSmall:
		ShapeSmall
	case _LayoutShapeNarrow:
		ShapeSmall
	else:
		LayoutS3
else: LayoutS3

LayoutS3-->
		report("Total Buildings", TotalBuildings)
		report("F,GFA2", GFA_Target)
		report("F,SplitAreaS2", SplitArea)
		report("F,Subdividable Area S2", SubdividableArea)
		set(Foundation_Height, scope.sy)
		set(LayoutSlope, geometry.angle(maxSlope))
		set(LayoutScopeSize, scope.sy)
		LayoutS4 (BuildingGFA)

_LayoutShapeSmall = scope.sx < Building_Depth || scope.sz < Building_Depth
_LayoutShapeNarrow = scope.sx > (scope.sz * narrownessRatio) || scope.sz >
(scope.sx * narrownessRatio)

LayoutS4 (ConstructArea) -->
	case Create_Units == true && (offsetDistance > 0 ):
		split(x){ ~Unit_Width:
Unit(split.index,split.total,(ConstructArea/split.total)) }*
	else:
		FootprintCheck(0,1, ConstructArea)

```

```
Unit(idx,n, ConstructArea) -->
	case n < 2 || offsetDistance <= 0:
		FootprintCheck(idx,n, ConstructArea)
	case Offset_Mode == "Increasing":
		split(z){ offsetDistance*(1-idx/(n-1)) :
GreenSpace("InsideUnit") | ~1: FootprintCheck(idx,n, ConstructArea) |
offsetDistance*idx/(n-1) : GreenSpace("InsideUnit") }
	case Offset_Mode == "Decreasing":
		split(z){ offsetDistance*idx/(n-1) : GreenSpace("InsideUnit") |
~1: FootprintCheck(idx,n, ConstructArea) | offsetDistance*(1-idx/(n-1)) :
GreenSpace("InsideUnit") }
	case Offset_Mode == "Alternating":
		split(z){ offsetDistance*(idx%2) : GreenSpace("InsideUnit") |
~1: FootprintCheck(idx,n, ConstructArea) | offsetDistance*((idx+1)%2) :
GreenSpace("InsideUnit") }
	case Offset_Mode == "Random":
		40% : split(z){				~1:
FootprintCheck(idx,n, ConstructArea) | offsetDistance  :
GreenSpace("InsideUnit") }
		10% : split(z){ offsetDistance/2: GreenSpace("InsideUnit") |
~1: FootprintCheck(idx,n, ConstructArea) | offsetDistance/2:
GreenSpace("InsideUnit") }
		40% : split(z){ offsetDistance  : GreenSpace("InsideUnit") | ~1:
FootprintCheck(idx,n, ConstructArea) }
		else: FootprintCheck(idx,n, ConstructArea)
	else:
		FootprintCheck(idx,n, ConstructArea)

FootprintCheck(idx,n, ConstructArea) -->
	case geometry.isConcave:
		cleanupGeometry(all, 0.1)
		convexify(Convexify_Value)
		comp(f){all: alignScopeToAxes(y) ConvexFd(idx,n,
ConstructArea)}
	else:
		cleanupGeometry(all, 0.1)
		Asd(idx,n, ConstructArea)

ConvexFd (idx,n, ConstructArea) -->
	case scope.sx >= mainWingWidth || scope.sz >= mainWingWidth:
		Asd(idx,n, ConstructArea)
	else:
		GreenSpace("ShapeSmall")

@Hidden
attr currentFloorIndex = 0
nFloorDetermine =
	case Max_Stories == 0: 30
	else: Max_Stories
foundationHeightAdjusted =
		case Foundation_Height + Foundation_Adjustment < 1 : 0
		else: Foundation_Height + Foundation_Adjustment

Asd (idx,n,ConstructArea) -->
```

```
		alignScopeToAxes(y)
		s('1,0,'1)
		Foundation
		t('0, foundationHeightAdjusted, '0)
		alignScopeToGeometry(yUp,largest, 1)
		Footprint(currentFloorIndex, nFloorDetermine, ConstructArea)

@Hidden
attr GFArea = 0
@Hidden
attr FirstFlArea = 0
@Hidden
attr FinalGFAReal = 0

Footprint(idx,n, ConstructArea) -->
		case ConstructArea < geometry.area (bottom) :
			case currentFloorIndex > nFloorDetermine:
				case Check_Stories == true:
					#Facade.GfarRoofSwitch(0)
					Facade.CheckStories
				else:
					RoofColor (0,Zoning.usageColor(Zoning.usagePerFloor(idx)))

			case currentFloorIndex <= nFloorDetermine:
				RoofColor (1,Zoning.usageColor(Zoning.usagePerFloor(idx)))
			else:
				NIL
		else:
			case idx == 0:
				alignScopeToAxes(y)
				GroundFloor (idx,n, ConstructArea)
				set (currentFloorIndex, idx +1)
				set(GFArea, geometry.area(bottom))
				comp (f) {top: Footprint(currentFloorIndex,n, (ConstructArea - geometry.area))}
			case idx == 1:
				alignScopeToAxes(y)
				t('0, getFloorHeight(idx-1), '0)
				extrude(getFloorHeight(idx))
				set (currentFloorIndex, idx +1)
				set(FirstFlArea, geometry.area(bottom))
				Floor(idx,n,Zoning.usagePerFloor(idx))
				comp (f) {top: Footprint(currentFloorIndex,n,(ConstructArea - geometry.area))}
			else:
				alignScopeToAxes(y)
				report("Building, Footprint Area (m2)", geometry.area)
				extrude(getFloorHeight(idx))
				set (currentFloorIndex, idx +1)
				Floor(idx,n,Zoning.usagePerFloor(idx))
```

```
				comp (f) {top: Footprint(currentFloorIndex,n,
(ConstructArea - geometry.area))}

Foundation -->
		case foundationHeightAdjusted > 0:
			case thematicsOn && Display_Thematics == "Usage":
				color(Zoning.usageColor(Zoning.usagePerFloor(0)))
				ForTaper
				FoundationSetback
			else:
				ForTaper
				FoundationSetback
		else: NIL

ForTaper -->
		envelope(world.up, LayoutScopeSize, 0, LayoutSlope)

FoundationSetback -->
		case Street_Setback_Mode == "Ground Floor Front":
			setback(Street_Setback_Distance){object.front: t(0,0,0.01)
BuildingSetbackHandler (0) | remainder: FoundationStep2 }
		case Street_Setback_Mode == "Ground Floor 3 Sides":
			setback(Street_Setback_Distance){
			object.front: t(0,0,0.01) BuildingSetbackHandler(0)|
			object.left: t(0,0,0.01) BuildingSetbackHandler(0) |
			object.right: t(0,0,0.01) BuildingSetbackHandler(0) |
			remainder: FoundationStep2}
		case Street_Setback_Mode == "Ground Floor 4 Sides":
			setback(Street_Setback_Distance){object.side: t(0,0,0.01)
BuildingSetbackHandler(0) | remainder: FoundationStep2 }
		case Street_Setback_Mode == "Random":
			30% : setback(Street_Setback_Distance){ object.front:
BuildingSetbackHandler(0) | remainder: FoundationStep2 }
			30% : setback(Street_Setback_Distance){ object.back:
BuildingSetbackHandler (0)| remainder: FoundationStep2 }
			else: FoundationStep2
		else:
			FoundationStep2

FoundationStep2 -->
			extrude(foundationHeightAdjusted)
			comp(f){side : Facade.Wall }

BuildingSetbackHandler(id) -->
		case foundationHeightAdjusted>0 && id == 0 :
			GreenSpace("InsideLot")
		case foundationHeightAdjusted>0 && id == 1 :
			NIL
		else: GreenSpace("InsideLot")

GroundFloor (idx,n, ConstructArea) -->
		case Street_Setback_Mode == "Ground Floor Front":
			setback(Street_Setback_Distance){object.front: t(0,0,0.01)
BuildingSetbackHandler(1) | remainder: GFEnvelope (idx,n, ConstructArea) }
```

```
		case Street_Setback_Mode == "Ground Floor 3 Sides":
			setback(Street_Setback_Distance){
			object.front: t(0,0,0.01) BuildingSetbackHandler(1)|
			object.left: t(0,0,0.01) BuildingSetbackHandler (1)|
			object.right: t(0,0,0.01) BuildingSetbackHandler (1)|
			remainder: GFEnvelope (idx,n, ConstructArea)}
		case Street_Setback_Mode == "Ground Floor 4 Sides":
			setback(Street_Setback_Distance){object.side: t(0,0,0.01)
BuildingSetbackHandler(1) | remainder: GFEnvelope (idx,n, ConstructArea) }
		case Street_Setback_Mode == "Random":
			30% : setback(Street_Setback_Distance){ object.front:
BuildingSetbackHandler(1) | remainder: GFEnvelope (idx,n, ConstructArea) }
			30% : setback(Street_Setback_Distance){ object.back:
BuildingSetbackHandler(1) | remainder: GFEnvelope (idx,n, ConstructArea) }
			else: GFEnvelope (idx,n, ConstructArea)
		else:
			GFEnvelope (idx,n, ConstructArea)

@Hidden
attr GroundFloorArea = 0
@Hidden
attr RealFar = 0

GFEnvelope (idx,n, ConstructArea) -->
			set(GroundFloorArea, geometry.area)
			report ("FAR, FA_Real", GroundFloorArea)
			set(RealFar,GroundFloorArea/ Parcel_Area)
			report ("FAR, FAR_Real", RealFar)
			extrude(getFloorHeight(0))
			Floor(idx,n,Zoning.usagePerFloor(idx))

Floor(idx,n,usage) -->
		set (FinalGFAReal, geometry.area (bottom))
		report ("FAR, GFA_Real", FinalGFAReal)
		report ("FAR, GFAR_Real", FinalGFAReal / Parcel_Area )
		report("Construction, Waste (kg)",
			FinalGFAReal * Zoning.constructionWastePerUsage(usage) *
(1-Building_Performance.Percent_Reduction_Construction_Waste))
		report("BPTarget, Waste, Domestic (kg/yr)",
			FinalGFAReal * Zoning.domesticWastePerUsage(usage) * (1-
Building_Performance.Percent_Reduction_Domestic_Waste))
		report("BPTarget, Energy, Heating Consumption (kWh/yr)",
			FinalGFAReal * Zoning.heatingConsumptionPerUsage(usage)
* (1-
Building_Performance.Percent_Reduction_Heating_Energy_Consumption))
		report("BPTarget, Energy, Electrical Consumption (kWh/yr)",
			FinalGFAReal * Zoning.electricConsumptionPerUsage(usage)
* (1-
Building_Performance.Percent_Reduction_Electric_Energy_Consumption))
		report("BPTarget, Water, Consumption (l/yr)",
			FinalGFAReal * waterConsumption(usage) * (1-
Building_Performance.Percent_Reduction_Water_Consumption))
		report("BPTarget, Water, Produced Greywater (l/yr)",
```

```
				FinalGFAReal * waterConsumption(usage) * (1-
Building_Performance.Percent_Reduction_Water_Consumption) *
Zoning.percentGreywaterProducedPerUsage(usage))
		report("BPTarget, Water, Produced Blackwater (l/yr)",
				FinalGFAReal * waterConsumption(usage) * (1-
Building_Performance.Percent_Reduction_Water_Consumption) * (1 -
Zoning.percentGreywaterProducedPerUsage(usage)))
		report("BPTarget, Water, Recycled Greywater (l/yr)",
				FinalGFAReal * waterConsumption(usage) * (1-
Building_Performance.Percent_Reduction_Water_Consumption) *
Zoning.percentGreywaterProducedPerUsage(usage) *
Building_Performance.Percent_Greywater_Recycled)
		ReportPerUsage (FinalGFAReal,usage)
		FloorVisual(idx,n,usage)
		StoryEdgeDisplay
		#extrude(getFloorHeight(idx))

FloorVisual(idx,n,usage) -->
		case Display_Thematics == "Usage":

		color(Color.ColorByUsage(Zoning.FunctionClassifier(Zoning.PlanFun
ction)))
				FloorMassFacades(idx,n)
		else:
				FloorMassFacades(idx,n)
RoofColor (sw,roofColor) -->
		case Display_Thematics == "Usage":
		Facade.GfarRoofSwitch(sw,roofColor)
		case Display_Thematics == "Zoning":

		Facade.GfarRoofSwitch(sw,Zoning.getZoningData_Color_Hex(Zoning.
PlanFunction))
		else:
				Facade.GfarRoofSwitch(sw,Solid_Color)

ReportPerUsage (area,usage) -->
		Zoning.ReportDemographics (area, usage)
		Zoning.ReportGFAUsages (area,usage)
		Zoning.ReportCosts (area,usage)

waterConsumption(usage) = Zoning.waterConsumptionPerUsage(usage) * (1-
Building_Performance.Percent_Reduction_Water_Consumption)
style Default

StoryEdgeDisplay -->
		case Story_Edge_Display :
				case coloringOn:
						Color.Black
						offset(0.2, border)
						extrude(-0.2) S.
				else:
						offset(0.2, border)
						extrude(-0.2) S.
		else: NIL
```

```
FloorMassFacades(idx,n) -->
		Facade.FloorMass(idx,n)

GreenSpace -->
	GreenSpace("main")

GreenSpace(id) -->
	case id == "GeneralSetback" : GreenSpace2 (General_Setback_GS)
	case id == "CommonBoundary" : GreenSpace2 (Lot_Buffer_GS)
	case id == "Split" : GreenSpace2 (Split_GS)
	case id == "InnerSetback" : GreenSpace2 (Inner_Setback_GS)
	case id == "ShapeSmall" : GreenSpace2 (Small_Shapes_GS)
	case id == "InsideLot" : GreenSpace2 (Inner_Lot_GS)
	case id == "InsideUnit" : GreenSpace2 (Inner_Lot_GS)
	case id == "Parking" : GreenSpace2 ("Parking")

	else:
		Green_Space.GreenSpace(id, thematicColor)

GreenSpace2 (type) -->
	case Zoning.Zoning_Display != "Envelope" :
		case type == "Pavers" :
			Green_Space.GreenSpace("hardscape",thematicColor)
		case type == "Hardscape & Lawn" :
			Green_Space.GreenSpace("openspace",thematicColor)
		case type == "Parking":
			ParkingRule.ParkingLot
		case type == "Random" : 25%: GreenSpace2 ("Pavers") 25%:
GreenSpace2 ("Hardscape & Lawn") 25%: GreenSpace2 ("LawnWtrees")
	else: GreenSpace2 ("Parking")
		else:

	Green_Space.GreenSpace("LawnWtrees",thematicColor)
	else:

	color(Zoning.getZoningData_Color_Hex(Zoning.PlanFunction))
		X.
```

Appendix B : Beylikduzu Implementation Plan Notes

BEYLİKDÜZÜ IMPLEMENTATIPON PLAN NOTES

* First four clauses are skipped in translation so that they are irrelevant to the topic of the thesis.

5. In comparison with the city development plans, the implementation of the development plans cannot be conducted before the technical and social reinforcement areas will be made public.

6. In comparison with the construction law no. 3194, in the green spaces and parks that are dedicated to public use the necessary reinforcements can be conducted providing the assent of power administration for 3m x 5m valve chamber, district regulator and transformer; telecommunication administration for telecom switchboard; and the respective departments for the technical infrastructure services.

7. Open and closed corbels are included to the floor area ratio. However, the terraces that are up to 3m wide on the ground are not included.

8. Free standing roofs and penthouses cannot be built. However, a penthouse can be built between the top floor and the roof but this area cannot exceed the 50% of the floor area. The attics that are in compliance with these conditions are not included to the floor area ratio.

9. The parcels with Energy Transmission Lines can use its development right providing the opinion of appropriateness from the relevant institutions and organizations.

10. It should be in compliance with the parking lot regulations.

11. It should be in compliance with the coastal law and regulations.

12. Parcel Sizes

12.1- The minimum parcel size cannot be under 600m2

12.2- Subject to not to subdivide, minimum parcel size and minimum parcel frontal terms are not required in the subdivision and amalgamation aimed at the border rectifications conducted with the purpose of assuring better conditions and facilitating the implementation.

12.3- Minimum parcel size and minimum parcel frontal terms are not required in the zoning areas that are in compliance with the law no. 2981 and 3290, 1st article of the appendix or 18. article of the construction law no. 3194 and the actual state will be taken into consideration.

13. In case of building more than one block within a single parcel, the distance between the blocks in the layout plan can be 4m providing that no windows will be opened for the constructions with Hmax=9.50m.

14. Town square, park, pedestrian way, car lots, cultural and administrative center, recreation facilities, tourism, housing (studio apartments), office services, open and closed exhibition centers, etc. will be included into the Special Project Sites that are specified in the plan.

15. Within the areas that are designated as the Municipal Service Areas facilities such as library, district mansion, theatre, cinema, multipurpose hall, registry office, cafe, recreational center, municipality’s additional service building, market, sports complex, parking lot and parking garage, etc. can be built.

16. In the reinforcement areas such as educational, health, cultural, religious facilities, public buildings, multi storey car park, municipality's service area that belong to public, the implementations can be performed in compliance with the preliminary design after the confirmation of the first tier municipality providing not to exceed the environmental structuring conditions.

17. Within the constructional areas that are specified in the plan only the facilities with the intended purpose can be built. The facilities cannot be used for anything other than the purpose specified in the plan.

18. The areas that are recommended as car park areas in the plans but privately-owned can be handled as parking lots (underground multi storey car park, above ground multi storey car park, lift car park) in accordance with the application of the relevant people and assent of the relevant institutions. During the implementation phase, the decree of Transportation and Traffic Regulation Commission will be abided concerning the entrances and exits.

19. – Within the planning area, providing the assent of Directorate of Parks and Gardens together with that of Directorate of Transportation Services, parking lots, playfields, open playgrounds, square, roads and junctions may be built; on condition that they are designed according to the zoning plan, the existing trees are taken into consideration and the original ground or leveled soil is below ground, there is enough depth of soil required for wooding and planting, they will be used as shelters in times of emergency and for regular situations as public owned "Multi Storey Underground Parking Lot" by the decision of Transportation and Traffic Regulation Commission.

20. "The parking lot demands of Industrial Areas and Housing Estate Areas will be settled within their own parcels. The assent of the Directorate of Transportation Services will be asked for regarding the function of the parking lot together with the entrances and exits in the implementation phase.

21. "Concerning the Trade Zones and Gas Stations; The assent of Transportation and Traffic Regulation Commission will be asked for regarding the function of the parking lot together with the entrances and exits in the implementation phase.

22. Bakırköy- Sefaköy- Beylikdüzü Rail System Line

22.1- The implementation will be conducted in comparison with the construction project that is approved by the Metropolitan Municipality.

22.2- The assents of relevant institutions and organizations (Water Supply and Sanitation in Istanbul, Directorate of Transportation Services, Directorate of Planning, Directorate of Soil and Earthquake Analysis, Directorate of Technical Works, Turkish Electricity Distribution Corporation, Turkish Electricity Generation and Transmission Corporation, Turkish State Railways, etc.) will be asked for in the construction project phase, the recommended precautions will be abided by and the rail system line route will be projected as tunnel, viaduct or grade crossing based on the land structure.

22.3- The implementation will be performed in accordance with the geological and geotechnical investigation reports.

23. Housing Zones

23.1- In detached-layout residential areas, for the parcels with less than 14m parcel frontal garden distance will be 3m. For the parcels with less than 12m parcel frontal amalgamation is required.

23.2- It is recommended that the parcels within the land consolidation borders will be agglomerated and settled with housing estate practice. To make it appealing, different floor are ratios are recommended for every other situation. For the areas with the housing functions within the consolidation borders, the specified structures are valid on condition that the amalgamation transactions will be actualized. ....

23.2.1- Within the borders of land consolidation, the parcels that are in line with the layout plan as part of the mass housing project prepared and approved by Beylikdüzü Municipality can be carried into action in stages by utilizing the rise in floor area ratios.

23.3- The floor, which is obtained by taking the original ground into consideration and on the level of first basement floor under the sub-basement grade of the building, can be inhabited on condition that the necessary pieces and the minimum dimensions stated in article 6.18 of the regulation together with the lighting and ventilation requirements stated in the article 6.17 are abided by.

23.4-

23.5- To carry out the urban transformation;

24- Trade Blocks

24.1- A shopping center, headquarters, accommodations, movie theatre, theatre, housing on the top floors can be located in the Central Business Districts. The structuring will be conducted according to the preliminary project. The mezzanines are included into the floor area ratio.

24.2- The structures that have trading service, bureaus, office buildings, restaurants, clubs, market place, multi-storey stores, banks, hotels, housing on the top floor can be located in the Trade Blocks. The mezzanines are included into the floor area ratio.

24.3- Basement and ground floors are for trading services and the top floors are for housing within the Trading + Housing spaces. The mezzanines are included into the floor area ratio.

24.4- Bureaus, office buildings, restaurants, clubs, market place, multi-storey stores, banks, hotels, cultural facilities like movie theatre and theatre, management-related structures, housing on the top floors and such functions can be located in Trade + Service spaces. The structuring will be conducted according to the preliminary project. The mezzanines are included into the floor area ratio.

24.5- Within the spaces that are planned as Trade+ Service+ Housing; private hospital, private training facility, multi-storey parking lot, cultural and social facilities, etc. can be located providing the assent of the relevant institutions (Ministry of Health, Ministry of Education, UKOME, Department of Fire Brigade). The structuring will be conducted according to the preliminary project. The mezzanines are included into the floor area ratio.

24.6- Independent offices can be organized on the basement floors of Central Business Districts, Trade + Housing, Trade + Service, Trade + Service + Housing on condition that the mechanical air-conditioning and lighting are available and fire regulations together with all other conditions of the regulations are fulfilled. The structuring will be conducted according to the preliminary project.

24.7- The areas that will be structured according to the preliminary project; Beylikduzu Municipality is authorized on the confirmation of the preliminary projects providing that the floor area ratio specified in the plan is protected.

24.8- The car park demand of the buildings within Central Business Districts, Trade, Trade + Service, Trade + Service + Housing will be met on the basement floor, however, these areas will not be used as commercial purpose and a car park with the capacity of four times larger than the minimum demand can be built underground on the back and side gardens of the buildings. This area is not included into the floor area ratio. The entrances and exits can be performed within the distance of the front garden.

24.9- The height of ground floor within the Central Business Districts, Trade, Trade + Housing, Trade + Service, Trade + Service + Housing is 5.50 m if mezzanine is constructed. The mezzanines are included into the floor area ratio.

24.10- For the lands that have trade + service + housing functions within the LAND CONSOLIDATION borders, the floor area ratio specified in the plan is valid and hmax will be 30.50 (40.50) if the amalgamation transactions are realized and floor area ratio will be increased 25%. For land consolidations, Beylikduzu Municipality is in charge of the changes that can be made in plans on condition that the m2 of road, green space, social reinforcement area will be preserved as it is and also of the subjects such as the residence in the layout plan of mass housing practice.

24.11- For the Central Business Districts, Trade, Trade + Housing, Trade + Service, Trade + Service + Housing projects that are 10.000-15.000 m2 – in block and in parcel- construction site can be 15% more than the ratio; for the projects that are over 15.000 m2 – in block and in parcel- construction site can be 25% more. The preliminary projects of these spaces will be prepared by the contractor in accordance with 1/1000 construction plan setback distance and be approved by Beylikduzu Municipality. The spaces other than the building sites within the property will be constructed in accordance with the preliminary project by the contractor as garden, park, playground, sports facility, car park areas. These spaces will not be left alone.

25- Industrial Areas

25.1- The areas planned as industrial area; the setback distance of front yard is 10m and the setback distance of side yard is 5m.

25.2- The areas planned as industrial area; the minimum parceling requirement is 2000 m2.

25.3- For the parcels, of which front is 25m or less than 25m, within the industrial area semi-detached structuring will be conducted. Within the industrial parcels, in which the parcel front is over 25m but the adjacent parcel front is less than 25m, semi-detached structuring conditions are valid.

26- Sheltering areas are not included into the floor area ratio.

27- The terms that are not mentioned in this report, construction law no. 3194 and the relevant regulations together with the conditions of İstanbul Construction Regulations are valid.

APPENDIX

28- The structuring conditions of housing, industry, one-day tourism, tourism and trade areas within Y.U.O areas E:0.05 Hmax:4.50

29- Central Business Districts and Trade Areas that are near E5 highway E: 3.00 hmax: and the structuring conditions of free standing order are E:2.50 hmax: 10 floors. Maximum storey height is 4 m. (If mezzanines are constructed, the storey height is maximum 7 m. The storey heights will be in line with the conditions of İstanbul Construction Regulations.)

30- Trade, Trade + Service areas; the structuring conditions of the parts with E:2.50 and hmax: free standing order E:2.00 hmax: 30.50.

31- Within the industrial areas with mass order structuring conditions buildings longer than hmax:9.50 cannot be constructed.

32- Beylikduzu Municipality cannot execute any projects that are not in accordance with 1/5000 scaled master development plan.

Appendix C Beylikduzu Implementation Plan Notes (Turkish).

1/1000 UYGULAMA İMAR PLAN NOTLARI

1 - Deprem yönetmeliğine uyulacaktır.

2 - Beylikdüzü İlk Kademe Belediyesi sınırlarında, farklı zaman dilimlerinde yapılmış Bayındırlık İskan Bakanlığı'nın ilgili birimlerince onaylanmış 8 bölgede yapılan jeolojik ve jeoteknik raporların uygulama şartları;

2.1 - 23.10.2003 onaylı Beko Bölgesine ait, jeolojik ve jeoteknik raporda belirlenen plan üzerinde tanımlı alanların uygulama şartları;

2.1.1 - Yerleşime Önlemli Alan-1(YÖ1)

Bu alanda inşa edilmesi planlanan yapı alanlarında ayrıntılı zemin etüt sonuçlarına bağlı olarak sert ve sıkı zemin derinliği belirlenmeli, yapı özellikleri ve deprem riski göz önüne alınarak zeminin taşıma gücü, oturma vb gibi zemin parametreleri detaylı olarak tespit edilerek, gerekli önlemler belirtilmelidir. Yerel olarak oluşabilecek zemin problemleri ayrıntılı zemin etütleri tespit edilmeli ve çözümler üretilmelidir.

2.1.2 - Yerleşime Önlemli Alan-2(YÖ2)

Bu alanda inşa edilmesi planlanan yapı alanlarında ayrıntılı zemin etütlerle sert ve sıkı zemin derinliği belirlenmeli, şev analizi yapılmalı, yapı özellikleri ve deprem riski göz önüne alınarak zeminin taşıma gücü, oturma vb gibi zemin parametreleri, ayrıca drenaj önlemleri ve şev duyarlılığı detaylı olarak tespit edilerek, gerekli önlemler belirtilmelidir. Bu alanlarda oluşabilecek her türlü şev istinad yapılarıyla desteklenmelidir. Bu alanda oluşturulan istinad yapı özellikleri, zemin etüt sonuçlarına bağlı olarak irdelenmeli, gerektiğinde takviye projesiyle desteklenmelidir. Yerel olarak oluşabilecek zemin problemleri ayrıntılı zemin etütleri tespit edilmeli ve çözümler üretilmelidir.

2.1.3 - Yerleşime Önlemli Alan-3(YÖ3)

Bu alanda inşa edilmesi planlanan yapı alanlarında ayrıntılı zemin etütlerle sıkı zemin derinliği tespit edilmeli, yapı özellikleri ve deprem riski göz önüne alınarak, oluşabilecek zemin deformasyonları ve bu deformasyonlara karşı engel olabilecek tarzda zemin ıslah yöntemleri ve bunlara uygun temel tipi belirlenmelidir. Ayrıca zeminin taşıma gücü, oturma vb gibi zemin parametreleri, drenaj önlemleri detaylı olarak tespit edilerek, gerekli önlemler belirtilmelidir.

2.2 - 1988 onaylı Yılmaz Konut Yapı Kooperatifine ait, geoteknik raporda belirlenen plan üzerinde tanımlı alanların uygulama şartları;

2.2.1 - Yerleşmeye Uygun Olmayan Alanlar (YUO)

185 m tesviye eğrisinin güneyinde yer alan arazi kesimi "eski heyelan" bölgesidir. Çok uzun süredir 185 m çizgisinde kuzeye (E5'e doğru) bir ilerleme olmamıştır.

2.2.2 - Yerleşime Uygun Olan Alanlar (YU)

Sahanın 185 m tesviye eğrisiyle E5 karayolu arasında yer alan bölümünde herhangi bir yamaç stabilitesi sorunu bulunmamaktadır. Bu bölümde inşa edilecek en az bir tam bodrum katlı yapıların 185 m çizgisine 30 m yaklaşmalarında herhangi bir sakınca görülmemektedir.

2.3 - 20.08.2002 onaylı Büyükşehir Konut alanına ait, jeolojik ve jeoteknik raporda belirlenen plan üzerinde tanımlı alanların uygulama şartları;

2.3.1 - Yerleşime Uygun Olmayan Alan (UO)

Bu alanda günübirlik ya da kalıcı olarak kesinlikle yapılaşma yapılmamalıdır.

2.3.2 - Önlem Alınmadan Yapılaşmaya İzin Verilmeyecek Alanlar

Tüm ÖA sınıflarındaki alanlar önlem gerektiren risk gerekçelerinin farklılığına bağlı olarak 3 ana başlık altında toplanmıştır.

2.3.2.1 - Önlem Alınarak Yapılaşmaya İzin Verilecek Alanlar 1 (ÖA1)

Bakırköy formasyonu kil ara seviyeli yer yer karstik boşluklar içeren kireç taşı jeolojik biriminden oluşmaktadır. Jeolojik etütlerde bu alanlarda 1zemin+5 normal kat önerilmiştir.

2.3.2.2 - Önlem Alınarak Yapılaşmaya İzin Verilecek Alanlar 2 (ÖA2)

Bakırköy formasyonu ve Güngören formasyonu arasındaki geçiş zonu ile dolgu alanlarından oluşmaktadır. Jeolojik etütlerde bu alanlarda 1zemin+5 normal kat önerilmiştir.

2.3.2.3 - Önlem Alınarak Yapılaşmaya İzin Verilecek Alanlar 3 (ÖA3)

Bakırköy formasyonu - Güngören formasyonu ve eski dolgu alanlarından oluşmaktadır. Jeolojik etütlerde bu alanlarda en az 1 bodrum + Max.2 kat önerilmiştir.

2.3.3 - Ayrıntılı Jeoteknik Etüd gerektiren alanlar (AJE)

Parsel Bazında çözüm üretmenin zor olduğu olası heyelan kuşakları ile eski heyelan oluşmuş alan tariflenmiştir. Aje alanında yapılması gereken tüm raporlar T.C Bayındırlık ve İskân Bakanlığı Afet İşleri Genel Müdürlüğüne onaylatılacaktır.

2.4 - 03.07.1996 onaylı 912 parsele ait, jeolojik raporda belirlenen plan üzerinde tanımlı alanların uygulama şartları;

2.4.1 - Yerleşime Uygun Olan Alanlar (YU)

Jeoteknik raporda yerleşmeye uygun alan olarak belirlenmiştir.

2.5 - Şubat 2001 onaylı Beykop Konut Yapı Koop. Ait, jeolojik raporda belirlenen plan üzerinde tanımlı alanların uygulama şartları;

2.5.1 - Yerleşime Uygun Olan Alanlar (YU)

Bu alan Güngören çok katı sert kıvamlı Kili biriminden oluşmaktadır. Bu alanın bütünü koşulsuz olarak yerleşime uygundur.

2.6 - Temmuz 1995 onaylı Megakent Kooperatifler Birliği'ne ait, jeolojik raporda belirlenen plan üzerinde tanımlı alanların uygulama şartları;

2.6.1 - Yerleşmeye Uygun Olmayan Alanlar (YUO)

Raporda bu alanlarda kalıcı yapılar yapılmasına izin verilmemiştir.

2.6.2 - Önlem Alınarak Yerleşime Uygun Alan(ÖA)

Bu alanlarda yerleşim yapılabilmesi için öncelikle sahayı iki yanından sınırlayan dere yataklarının ıslahı ve kenarlarının aşınmaya karşı korunması gerekmektedir. Bu amaçla uygulanabilecek önlemler raporda belirtilmektedir.

2.6.3 - Yerleşime Uygun Alanlar(YU)

Raporda değinilen zemin ve temellerle ilgili uyarılara uyulmak koşulu ile çok katlı ya da az katlı konut yapılarının yapılmasında sakınca yoktur.

2.7 - 25.01.2001 onaylı Adakent Konut Yapı Kooperatifine ait, jeolojik raporda belirlenen plan üzerinde tanımlı alanların uygulama şartları;

2.7.1 - Önlem Alınarak Yerleşime Uygun Alanlar (ÖA)

İki parça halinde kazıklı önlemlerin alınarak, alınan bu önlemlerin yeterliliğinin uzman bir jeoteknik ekibince, şev stabilite analizlerini içeren bir metotla irdelenmeli ve gereğinde yeni önlemlerin alınması gerekmektedir.

2.7.2 - Yerleşmeye Uygun Alanlar (YU)

Bu alanlarda raporda değinilen zemin ve temellerle ilgili uyarılara uyulmak koşulu ile yapı yapılmasında sakınca yoktur.

2.8 - 25.11.1999 onaylı 142-143-144 adalara ait, jeolojik ve geoteknik raporda belirlenen plan üzerinde tanımlı alanların uygulama şartları;

2.8.1 - Yerleşmeye Uygun Olmayan Alanlar (YUO)

Raporda bu alanlarda kalıcı yapılar yapılmasına izin verilmemeli ve raporda belirtilen önlemlerin alınması gerekmektedir.

2.8.2 - Önlem Alınarak Yerleşime Uygun Alanlar (ÖA)

Alınması gereken önlemler, öncelikle sahayı doğudan sınırlayan derenin, yamacın geniş bölümündeki durağanlığı olumsuz etkileyen aşındırıcı etkisinin ortadan kaldırılmasını sağlamalıdır. Bunun için dere yatağının mutlaka islah edilmesi gerekmektedir. Bu alanla ilgili raporda belirlenen önlemlerin alınması koşulu ile yapılaşmaya gidilecektir.

2.8.3 - Yerleşime Kısıtlı Olarak Uygun Alanlar (KYU)

Bu alanlara ilişkin yapılacak yapıların temelleri ya doğrudan doğruya Çukurçeşme kumu tabakasına ya da bunun altındaki Gürpınar kiline yerleştirilecektir. Bu nedenle taşıma gücü açısından kat sayısına bir kısıtlama getirilmesi gerekmemektedir.

2.8.4 - Yerleşmeye Uygun Alanlar (YU)

Bu alanlarda raporda değinilen zemin ve temellerle ilgili uyarılara uyulmak koşulu ile yapı yapılmasında sakınca yoktur.

2.9 - Temmuz 1991 onaylı Emlak Bankası Konut Yapı Kooperatifi'ne ait jeolojik ve geoteknik raporda belirlenen plan üzerinde tanımlı alanların uygulama şartları;

2.9.1 - Yerleşime Uygun Olmayan Alan (YUO)

Vadi içerisinde yer alan eski heyelanların belirli ölçüde heyelan potansiyeli taşıması nedeniyle vadi içinde yapılaşmaya gidilmemesi önerilmektedir.

2.9.2 - Yerleşime Uygun Alan (YU)

9-16 katlı yüksek binalarda gerek taşıma yükü, gerekse heyelan potansiyeli açısından herhangi bir sakınca görülmemektedir.

2.10 - 03.07.2001 onaylı Güney Kesimine ait, jeolojik raporda belirlenen plan üzerinde tanımlı alanların uygulama şartları;

2.10.1 - Yerleşmeye uygun olmayan alanlar (YUO)

Bu alanlar ile ilgili Afet İşleri Genel Müdürlüğü onaylı Yerleşime Uygunluk Amaçlı Jeoloji Araştırmasında; "yeni ve ayrıntılı araştırmalar yapılıp belirlenecek önlemler alınmadıkça yerleşime uygunluk yönünde bir uygulamaya gidilmemelidir"

2.10.2 - Ayrıntılı Jeoteknik Etüd gerektiren alanlar (AJE)

Planda (AJE) olarak tanımlanmış alanlarda yapı ruhsatına esas olarak ayrıntılı jeoteknik araştırma ile zemin kesiti, eski heyelanlara ilişkin kayma yüzeyleri, zemin mekaniği parametreleri, yeraltı suyu durumu belirlenecektir. Hazırlanan raporlar Afet İşleri Genel Müdürlüğü'nün İlgili birimlerince onaylanacaktır.

2.10.2.1 - AJE (1)

Planda AJE (1) simgesi ile belirtilen yeni ve diri heyelanlı alan ilk yağışlı dönemde, üzerindeki hasarlanmaya başlamış yapılarla can güvenliğini de tehlikeye düşürecek şekilde hızlanacağı için yıl içinde bir bütün olarak sondajlı araştırma yapılıp gereken önlemlerle denetim altına alınmalıdır. Bu araştırmalar ışığında gereken önlemler alınmak kaydı ile Afet İşleri Genel Müdürlüğü'nün İlgili birimlerince önerileri doğrultusunda planda belirlenen yapılanma koşullarına göre yapılanacaktır.

2.10.3 - Yerleşime Önlem Alınarak Uygun Olan Alanlar (ÖAYU)

Bu alanlara ancak önlem alınarak yerleşilebilir komşu parsellerin güvenliği sağlanmadan kazı ve dolguya, drenaj koşullarını bozacak uygulamalara izin verilmeyecektir.

2.10.3.1 - Yerleşime Önlem Alınarak Uygun Olan Alanlar 1(ÖAYU) (1)

Planda ÖAYU (1) olarak tanımlı alanlarda maksimum bina yüksekliği 2 (İki) kat olacaktır.

2.10.3.2. - Yerleşime Önlem Alınarak Uygun Olan Alanlar 2 (ÖAYU) (2)

Planda ÖAYU (2) olarak tanımlı alanlarda maksimum bina yüksekliği 3 (üç) kat olacaktır.

2.10.3.3 - Yerleşime Önlem Alınarak Uygun Olan Alanlar 3 ÖAYU (3)

Planda ÖAYU(3) olarak tanımlı alanlarda onaylı jeolojik rapordaki şartlara uyulacaktır.

2.10.4 - Yerleşime Uygun Olan Alanlar (YU)

Raporda belirlenen koşullara uyulacaktır. Bakanlığın yönetmelik ve genelgeleri ile istenen zemin araştırmaları ve değerlendirmeleri yapılmalı, yapı ve temelle ilgili kararlar buna göre alınmalıdır.

3 - Beylikdüzü İlk Kademe Belediyesi sınırlarında, farklı zaman dilimlerinde yapılmış Bayındırlık İskan Bakanlığı'nın ilgili birimlerince onaylanmış 10 bölgede

yapılan jeolojik ve jeoteknik raporlarda önerilen kat yüksekliklerinin aşılması durumunda hazırlatılacak jeolojik etüd raporu Afet İşleri Genel Müdürlüğü'nün ilgili birimince onaylatılacaktır. Raporun sonuç ve öneriler kısmında belirtilen hususlara uyulacaktır.

4. - Beylikdüzü İlk Kademe Belediyesi sınırlarında, farklı zaman dilimlerinde yapılmış Bayındırlık İskan Bakanlığı'nın ilgili birimlerince onaylanmış 10 bölgede yapılan jeolojik ve jeoteknik raporlarda belirtilen yerleşmeye uygun olmayan alanlarda "yeni ve ayrıntılı araştırmalar yapılıp belirlenecek önlemler alınmadıkça yerleşime uygunluk yönünde bir uygulamaya gidilmemelidir" denmektedir. Bu alanların bir kısmı onaylı jeolojik rapor doğrultusunda yapılaşma dışında bırakılarak yeşil alan olarak düzenlenmiştir. Bir kısmına planda 1 katlı yapılaşma izni verilmiş, bir kısmı da sosyal donatı alanı olarak ayrılmıştır. 1 katlı yapılaşma izni verilen bölgelerde; zeminin sondaja dayalı jeolojik ve geoteknik araştırmaları, ayrıntılı jeolojik etüt raporu hazırlanacak ve Afet işleri Genel Müdürlüğü'nün ilgili birimlerince onaylanacaktır. Etütler sonucunda yerleşime uygunluk açısından aksi bir durum olmadığının anlaşılması durumunda gerekli önlemler alınarak tek katlı yapılaşmaya müsaade edilecek ve inşaat alanının her 20 m²'sine karşılık en az 1 ağaç dikilecektir. Şayet tekrar ve daha detaylı yaptırılan etütlerde de parsel yerleşmeye uygun olmayan alan tanımında olursa ağaçlandırılacak alan olarak düzenlenecektir. Sosyal donatı alanı olarak ayrılan alanlarda yeniden hazırlatılacak jeolojik etüd raporu Afet İşleri Genel Müdürlüğü'nün ilgili birimince onaylatılacaktır. Raporun sonuç ve öneriler kısmında belirtilen hususlara uyulacaktır.

5 - İmar Planlarına göre Teknik ve sosyal donatı alanları kamu eline geçmeden imar uygulaması yapılamaz.

6 - 3194 sayılı imar kanununa göre kamuya terk işlemi yapılmış olan yeşil alan ve park alanlarında, Bedaş Genel Müdürlüğünün uygun görüşü alınmak kaydıyla 3mx5m ebadında vana odası, bölge regülatörleri ve trafo, Telekom'un uygun görüşü alınmak kaydıyla Telekom santrali ve ilgili birimlerin uygun görüşleri alınmak kaydıyla teknik alt yapı hizmetleri için gerekli donatılar yapılabilir.

7 - Açık ve kapalı çıkmalar emsale dahildir. Ancak zemine oturan genişliği 3m ye kadar olan teraslar emsale dahil değildir.

8 - Bağımsız çatı ve çekme kat yapılamaz. Binanın son katı ile bağlantılı çatı arası yapılabilir ancak bu alan kat alanının % 50 sini geçemez. Bu şartlara uyun çatı katları emsale dâhil değildir.

9 - Enerji Nakil Hattı geçen parseller, ilgili kurum ve kuruluşlardan uygun görüş alınması koşuluyla imar hakkını kullanabilir.

10 - Otopark yönetmeliğine uyulacaktır.

11 - Kıyı kanunu ile yönetmeliğine uyulacaktır.

12 - Parsel Büyüklükleri

12.1 - Minimum parsel büyüklüğü 600 m² den az olamaz

12.2 - Yeni parsel oluşturmamak koşulu ile mevcut parsellerde daha uygun şartlar sağlamak ve uygulamayı kolaylaştırmak amacı ile yapılacak sınır düzeltmesine yönelik ifraz ve tevhit işlemlerinde minimum parsel büyüklüğü ve minimum parsel cephesi şartı aranmaz.

12.3 - 2981 ve 3290 sayılı yasa, ek 1 madde veya 3194 sayılı imar kanununun 18. maddesine göre yapılacak imar uygulaması alanlarında minimum parsel büyüklüğü ve minimum parsel cephesi şartı aranmayacak fiili durum dikkate alınacaktır.

13 - Bir parsele birden fazla blok yapılması durumunda vaziyet planında yerleştirilecek blokların birbirlerine olan mesafesi, Hmax=9.50m olan yapılarda pencere açmamak koşulu ile 4 m olabilir.

14 - Planda belirtilen Özel Proje Alanlarında kent meydanı, kent parkı, yayalaştırılmış alanlar, otoparklar, kültür ve yönetim tesisleri, eğlence ve rekreasyon, turizm, konut(stüdyo tipi), büro hizmetleri, açık kapalı gösteri alanları gibi fonksiyonlar yer alacaktır. Avan Projeye göre uygulama yapılacaktır. inşaat emsali 0,25'tir. Proje alanı içerisinde yer alan ticaret, kültür, sağlık, karakol gibi farklı fonksiyon alanları bu emsalin dışında tutulacaktır.

15 - Belediye Hizmet Alanı olarak ayrılmış alanlarda, kütüphane, semt konağı, tiyatro, sinema, çok amaçlı salon, nikah dairesi, çay bahçesi, eğlence ve dinlenme merkezi, belediye ek hizmet binaları, belediye çarşısı, spor tesisi, kapalı ve açık otoparklar vb belediye hizmetleri ile ilgili tesisler yapılabilir.

16 - Eğitim, sağlık, kültür, dini tesis, resmi tesis (itfaiye, TEK..) katlı otopark, belediye hizmet alanı gibi kamuya ait donatı alanlarında çevre yapılanma koşullarını aşmamak şartı ile ilk kademe Belediyesince onaylanarak avan projeye göre uygulama yapılır.

17 - Planda belirtilen kullanım alanlarında, kullanım amacı dışında hiçbir tesis yapılamaz. Yapılacak tesisler sonradan hiçbir biçimde planda gösterilen amaç dışında kullanılamaz.

18 - Planlarda otopark alanı olarak önerilen ve mülkiyeti şahıslara ait olan alanlar için ilgililerin müracaatı ve ilgili kurumların uygun görüşleri doğrultusunda özel otopark alanı (zemin altı katlı otopark, zemin üstü katlı otopark, asansörlü otopark) olarak uygulama yapılabilir. Uygulama aşamasında otopark giriş-çıkışları konusunda Ulaşım ve Trafik Düzenleme Komisyonu (UTK) kararı alınacaktır.

19 - Planlama alanı içinde, Park ve Bahçeler Müdürlüğü, Ulaşım Daire Başkanlığı v.b. kurumların uygun görüşleri alınmak koşulu ile açık yeşil ve park alanları, spor alanları, çocuk bahçeleri, meydan, yol ve kavşak alanları gibi kamuya açık alanların zeminaltları ağaç ve bitki yaşamının sürdürülebileceği toprak derinliği bırakılarak ve doğal zemin kodları değiştirilmeyecek biçimde, olağanüstü durumlarda sığınak alanı olarak, diğer zamanlarda ise, Ulaşım ve Trafik Düzenleme Komisyonu (UTK) kararıyla kamuya ait "Zemin altı Katlı Otopark" olarak kullanılmak üzere düzenlemeler yapılabilir.

20 - "Sanayi Alanları ve Toplu Konut Alanlarının otopark ihtiyacı kendi parselleri içinde çözümlenecektir. Uygulama aşamasında otopark fonksiyonu ve tesis giriş-çıkışları hususunda Ulaşım Daire Başkanlığı'nın görüşü alınacaktır."

21 - "Ticaret Alanları, Akaryakıt İstasyonları ile ilgili olarak uygulama aşamasında otopark fonksiyonu ve tesis giriş-çıkışları hususunda parsel bazında Ulaşım ve Trafik Düzenleme Komisyonu Kararı'nın (UTK) alınması gerekmektedir.

22 - Bakırköy-Sefaköy-Beylikdüzü Raylı Sistem Hattı

22.1 - Uygulama; Büyükşehir Belediye Başkanlığınca onanacak uygulama projesine göre yapılacaktır.

22.2 - Uygulama projesi aşamasında; ilgili kurum ve kuruluş görüşleri (İSKİ , Ulaşım, Planlama Müdürlüğü, Zemin Deprem İnceleme Müdürlüğü, Teknik İşler Müdürlüğü, TEDAŞ,TEAŞ, TCK,TCDD,...vb) alınarak, önerilen tedbirlere uyulacak ve raylı sistem hattı güzergahı arazi yapısına bağlı olarak tünel, viyadük ve hemzemin olarak projelendirilecektir.

22.3 - Jeolojik ve jeoteknik etüt raporları doğrultusunda uygulama yapılacaktır.

23 - Konut Alanları

23.1 - Ayrık Nizam Konut alanlarında, parsel cephesi 14m den küçük parsellerde bahçe mesafesi 3m olacaktır. Parsel cephesi 12m den küçük olan parsellerde tevhit şartı getirilecektir.

23.2 - ARAZİ TOPLULAŞTIRMA Sınırı içerisinde yer alan parsellerin; birleştirilmesi ve Toplu konut uygulaması ile yapılaşması önerilmiştir. Bunun cazip hale gelmesi için her koşul için farklı yapı emsalleri önerilmiştir. Toplulaştırma sınırı içerisinde yer alan konut fonksiyonu olan alanlarda, belirtilen yapı düzenleri parsellerin tevhit işlemlerinin gerçekleştirilmesi ve ada bazında yapılaşması halinde geçerlidir. Toplu konut uygulaması içerisinde yapılaşacak konut parsellerinde, minimum 2 ha'lık imar parselleri ve yapı adalarının oluşturulması koşulu ile yapılaşacak parsellerde hmax=30.50(40.50M)m olacak, yapı emsali % 55 arttırılacaktır. Münferit yapılaşacak parseller hmax değişmemek koşulu ile toplulaştırma işlemi ile oluşacak yapı emsalinden % 55 azaltılacaktır. Arazi toplulaştırmalarında yol, yeşil alan, sosyal donatı alanı vb alanların planda ayrılan m²'lerinin korunması koşulu ile yer değişikliğinin yapılması ve toplu konut uygulaması vaziyet planındaki kitle oturumları gibi konularda Beylikdüzü Belediyesi yetkilidir.

23.2.1 - ARAZİ TOPLULAŞTIRMASI sınırları içerisinde Beylikdüzü Belediyesi'nce hazırlatılıp onaylanan toplu konut uygulama projesi kapsamında hazırlanacak vaziyet planına uygun parseller etaplar halinde emsal artışından faydalanarak uygulamaya geçebilir.

23.3 - Binanın su basman kotunun altında 1. bodrum kat seviyesinde, doğal zemini bozmamak şartı ile kazanılan kat, yönetmeliğin 6.18. maddesindeki konutlarda bulunması zorunlu piyesler ve en az ölçülerine uyulması ve 6.17. maddesinde belirtilen ışıklandırma ve havalandırma şartlarına uyması koşulu ile iskan edilebilir.

23.4 - Yapılanma koşulları Taks=0.25 2 kat ve Taks=0.30 3 kat olan bölgelerde, imar parsellerinin 1.5 ha. ve üzerinde olması halinde, Taks=0.25 2 katlı yerler E=0.75 Hamax=9.50, Taks=0.30 3 katlı yerler E=1.50 Hmaks=15.50 olarak yapılaşacaktır. Bu alanlarda toplu konut uygulaması yapılabilecek, planda belirtilen TAKS (taban alanı kat sayısı) değişmemek koşulu ile Avan projeye göre yapılaşacaktır. Avan projede yol, yeşil alan ve kitle oturumları gibi konularda Beylikdüzü Belediyesi yetkilidir.

23.5 - Kentsel Dönüşümü sağlamak için; Taban alan kat sayısı verilen yerlerde ada bütününde veya minimum 3.000-5.000 m² arasında olan ada bazında ve parsel bazında yapılacak uygulamalarda, inşaat alanı kat sayı değerinin % 20 fazlası, 5.000 ve üzeri olan ada bazında ve parsel bazında yapılacak uygulamalarda, inşaat alanı katsayı değerinin % 30 fazlası kullanılabilir. Hazırlanacak avan proje 1/1000 ölçekli imar planı çekme mesafelerine uygun olarak girişimci tarafından hazırlanacak ve Beylikdüzü Belediyesi'nce onanacaktır. Bu alanlarda taban alanı katsayısı kat adetine göre hesaplanır ve hiçbir şekilde 0.40'tan fazla olamaz. Kat yükseklikleri 03.07.2001 onaylı jeolojik raporda belirlenen plan üzerinde tanımlı alanların uygulama şartları hükümlerince belirlenecektir.

24 - Ticaret Alanları

24.1 - M.İ.A. (Merkezi İş Alanları) Alışveriş- veriş merkezi, yönetim merkezleri, konaklama tesisleri, sinema, tiyatro salonları, normal üst katlarda konut, vb. fonksiyonlar yer alabilir. Avan projeye göre yapılaşacaktır. Asma katlar emsale dahildir.

24.2 - Ticaret (T) alanlarında ticari hizmet veren yapılar, bürolar, işhanları, lokanta, gazino, çarşı, çok katlı mağazalar, bankalar, oteller, normal üst katlarda konut vb. fonksiyonlar yer alabilir. Asma katlar emsale dahildir.

24.3 - Ticaret + Konut (T+K) olarak planlanan alanlarda; bodrum ve zemin katlarda ticaret olmak üzere üst katlarda konut kullanımı olacak alanlardır. Asma katlar emsale dahildir.

24.4 - Ticaret + Hizmet (T+H) olarak planlanan alanlarda; bürolar, işhanları, gazino, lokanta, çarşı, çok katlı mağazalar, bankalar, oteller, sinema, tiyatro gibi kültürel tesisler, yönetimle ilgili tesisler, normal üst katlarda konut ve benzeri fonksiyonlar yer alabilir. Avan Projeye göre yapılaşacaktır. Asma katlar emsale dahildir

24.5 - Ticaret +Hizmet +Konut (T+H+K) olarak planlanan alanlarda; T+H alanlarında yapılanların yanı sıra konut kullanımı ve ilgili kamu kurum ve kuruluşlarından uygun görüş alınmak koşulu ile (Sağlık Bakanlığı, Milli Eğitim Bakanlığı, UKOME, İtfaye Daire Başkanlığı) Özel Hastane, Özel Eğitim Tesisi, Katlı Otopark, Kültür ve Sosyal tesis vb fonksiyonlar yapılabilir. Avan Projeye göre yapılaşacaktır. Asma katlar emsale dahildir

24.6 - M.İ.A, T, T+K, T+H, T+H+K alanlarının bodrum katlarında, mekanik havalandırma ve ışıklandırma yapılması ve yürürlükteki yangın mevzuatına ve yönetmelikteki diğer şartlara uyulması halinde bağımsız işyeri tertiplenebilir. Bu uygulama avan proje ile yapılacaktır.

24.7 - Avan projeye göre yapılaşacak alanlarında; planda belirlenmiş olan emsalin korunması şartıyla Avan projelerin onaylanmasında Beylikdüzü Belediyesi yetkilidir.

24.8 - MİA, T, T+H, T+H+K alanlarında yapılacak binaların otopark ihtiyacı; öncelikle bodrum katta karşılanması, ticari amaçla kullanılmaması ve bina cephe hattı gerisinde kalmak şartı ile binaların arka ve yan bahçelerinde tabi zemin altında minimum ihtiyacın 4 katına kadar otopark yapılabilir. Bu alan emsale dahil değildir. Otopark giriş çıkışı ön bahçe mesafesi içinden de sağlanabilir.

24.9 - M.İ.A, T, T+K, T+H, T+H+K alanlarında zemin kat yüksekliği; asma kat yapılması halinde 5.50m dir. Asma katlar emsale dahildir.

24.11 - ARAZİ TOPLULAŞTIRMA Sınırı içerisinde yer alan ticaret+hizmet+konut fonksiyonu olan alanlarda, planda belirtilen yapı emsalleri geçerli olup parsellerin tevhit işlemlerinin gerçekleştirilmesi ve ada bazında yapılaşması halinde hmax=30.50(40.50)m olacak, yapı emsali % 25 arttırılacaktır. Arazi toplulaştırmalarında yol, yeşil alan, sosyal donatı alanı vb alanların planda ayrılan m²'lerinin korunması koşulu ile yer değişikliğinin yapılması ve toplu konut uygulaması vaziyet planındaki kitle oturumları gibi konularda Beylikdüzü Belediyesi yetkilidir.

24.12 - M.İ.A., T, T+K, T+H, T+H+K alanların büyüklüğü 10.000-15.000 m² arasında olan ada bazında ve parsel bazında yapılan uygulamalarda, inşaat alanı kat sayı değerinin % 15 fazlası, 15.000 m² ve üzerinde olan ada bazında ve parsel bazında yapılan uygulamalarda, inşaat alanı kat sayı değerinin % 25 fazlası olarak verilebilir. Bu alanlarda avan proje 1/1000 ölçekli imar planı çekme mesafelerine uygun olarak girişimci tarafından hazırlanacak ve Beylikdüzü Belediyesi'nce onanacaktır. Mülkiyet sınırları içinde bina yerleştirilen alanlar dışında kalan, bahçe, park, çocuk bahçesi, oyun-spor alanları, otopark alanları ve ada içi yollar avan projesine uygun olarak girişimci tarafından gerçekleştirilecektir. Bu alanlar kamuya terk edilmeyecektir.

25 - Sanayi Alanları

25.1 - Sanayi alanı olarak planlanan alanlarda; ön bahçe çekme mesafesi 10m, yan bahçe çekme mesafesi 5m dir.

25.2 - Sanayi alanı olarak planlanan alanlarda; minimum ifraz şartı 2000m2 dir.

25.3 - Sanayi alanlarında cephesi 25m ve 25m' den az olan parsellerde ikiz nizam yapılaşmaya gidilecektir. Parsel cephesi 25m den büyük olup bitişiğindeki parsel cephesi 25m den küçük sanayi parsellerinde ikiz nizam yapılaşma şartları geçerlidir.

26 - Sığınak alanları emsale dâhil değildir.

27 - Bu Plan ve Raporunda belirtilmeyen hususlarda 3194 sayılı İmar Kanunu ve bağlı yönetmelikleri ile İstanbul İmar Yönetmeliği hükümleri geçerlidir.

PLAN NOTU İLAVESİ

28- Y.U.O. alanlarda bulunan konut, sanayi, günübirlik turizm, turizm ve ticaret alanlarındaki yapılanma koşulları E:0.05 Hmax:4.50 dir.

29- E5 karayoluna paralel olan MİA ve Ticaret Alanlarındaki E:3.00 hmax:sebest Nizam olan yerlerin yapılanma koşulları E:2.50 hmax:10(SERBEST) kattır. Max kat yüksekliği 4 m.(Asmakat yapılacak zemin katlarda kat yüksekliği max 7m dir.Bütün katlarda kat yüksekliği İ.İmar yönetmeliği şartlarında olacaktır.) (04.09.2008 tarih ve 19 sayılı belediye meclis kararı)

Emsal meri imar planı şartlarında kalmak kaydıyla çıkma yapılamaz.

30- T, T+H alanlarında ki E:2.50 hmax:serbest nizam olan yerlerin yapılanma koşulları E:2.00 hmax:30.50 dir.

31- Kitle nizam yapılanma koşulu getirilen sanayi alanlarının da hmax:9.50 den yüksek yapı yapılamaz.

32-Beylikdüzü Beldesi Mer'i 1/5000 ölçekli nazım imar planına aykırı uygulama yapılamaz.

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