ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

ARCHITECTURE OF CONSTRAINTS: A MASS CUSTOMIZATION ORIENTED APPROACH FOR HOUSING DESIGN

M.Sc. THESIS

Bengisu İLKSOY

Department of Architecture

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

KISITLARLA TANIMLANAN MİMARLIK: KİTLESEL ÖZELLEŞTİRME ODAKLI KONUT TASARIMI

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Bengisu İlksoy, a **M.Sc.** student of ITU **Graduate School of Science Engineering and Technology** student ID **502121103**, successfully defended the **thesis** entitled "**ARCHITECTURE OF CONSTRAINTS: A MASS CUSTOMIZATION ORIENTED APPROACH FOR HOUSING DESIGN**", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To my family,

FOREWORD

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May 2015 Bengisu İLKSOY
(Architect)

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ABBREVIATIONS

CAD	**:** Computer Aided Design
CAM	**:** Computer Aided Manufacturing
MC	**:** Mass Customization
MP	**:** Mass Production
BIM	**:** Building Information Systems
SQM	**:** Squaremeter
TOKI	**:** Housing Development Administration of Turkey
CSP	**:** Constraint Satisfaction Problem
TOC	**:** Theory of Constraints
OOP	**:** Object Oriented Programming

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ARCHITECTURE OF CONSTRAINTS: A MASS CUSTOMIZATION ORIENTED APPROACH FOR HOUSING DESIGN

SUMMARY

Customized production involves a high degree of manual work and customization requires increased effort and time. Consequently, these tasks have often resulted in a price increase that is higher than what most consumers can afford. Differently, mass production is the name given to the method of producing goods for masses at low costs. The process itself is characterized by mechanization to achieve high volume production, interchangeable parts and a division of labor. Organizational management concepts are needed to be developed for the stages of manufacturing and enhancing the quality standards. It also requires a high level of demand in order to get an effectiveness from this kind of production.

With reduction in labor costs, as well as increased rate of production, mass production enables a company to produce larger quantities of a product at a lower cost and with a small work force than that of traditional, non-linear methods. Major experiments that eventually led to mass production were first performed for the use of military organizations. Since then, the method was started to be applied for the production of everyday goods to satisfy the increasing demand. Ultimately, use of mass production has rapidly increased the supply but in the longer term limited the individual's choice. Although it was a significant innovation in the history of industrial design, the result is a standardized product made in a fairly small number of variety.

Instead of mere repetition of the same element, mass industry is capable of producing individual, customized products as well. It is possible to simultaneously achieve the tailor-made quality along with industrialized speed and cost effectiveness. This approach, describing the oxymoron of mass producing customized products, is called mass customization. In the last decades, most industries have put much effort into formalizing this hybrid character of mass customization that offers both a satisfaction of user needs at a high standard and an affordable cost in virtue of mass production. The key point is to not consider it as a stand-alone business strategy that is slowly replacing the production and distribution systems of today, but as a set of organizational capabilities that can supplement and enrich an existing system. Therefore, it is crucial to re-build the process so as to be more flexible by using computer aided design and manufacturing systems (CAD/CAM technologies). It is also essential to include the user in the system effectively while using the computer as a digital factory.

Most industries, *e.g.* automotive, computer, and clothing, have been using mass customization methods for several decades. For example, Dell as one of the leading computer manufacturers, allows customers specify hardware and software of their choice online and market them according to their needs. Another example is Nike, a sports footwear brand that allows the customer to make their own customized choice from a variety of materials, colors and patterns to create a unique pair of footwear in accordance with their own sense of style. After specifications are submitted electronically to the manufacturing facility, product is delivered directly to the customer's address in three weeks. However, mass customization has been slow to gain traction in the architectural industry due to high complexity of buildings and the required involvement of several different professions in design and building process, even though it is crucial to focus on mass customization especially for development of housing where no two users are the same. Accordingly, the typical practice of the user choosing the best plan type from a limited number of preset options is inefficient in a broader sense and despite the fact that architects design options, the options cannot be modified. Nevertheless, a house is expected to reflect its owner as it is not a mere ordinary daily use product but a home, a place where one should feel completely comfortable.

Definitions of what constitutes social housing vary greatly, from one country to another. In Latin America, the term is occasionally used for formal housing built for poor people by private sector companies and is often subsidized. As for Turkey, most of the cities have seen a rapid population growth and urbanization for the second half of the last century which is causing an urban sprawl. Especially Istanbul has been negatively affected by this kind of overcrowdedness. Consequently, the government has established TOKI (Housing Development Administration-Toplu Konut İdaresi) an administration that aims to meet the rapidly growing demand for affordable housing in a planned manner. Although the institution later has widened its scope, the main purpose has been to meet low and middle income groups' needs by producing mass houses. One of the most obvious characteristics of this sector is constructional and structural standardization as well as a homogenized housing typology that pays little regard to variables such as climate, land and culture. It also falls short in answering to the different characteristics and varying needs of occupants and results in the discomfort and otherization of them. Considering that some people do not even have the chance to choose the size, plan type or location of their homes, customization is an essential need especially for mass-produced social housing.

It is, however, a challenge to effectively implement mass customization in architecture compared to other fast moving consumer goods such as computers or cars. While other industries are able to offer a broad range of alternatives and changeable components, architecture stands in a different status, because of its much more complex nature. Another difficulty in the way of application of mass customization in architecture is the requirement of participation of buyers in the design process in order to give them more freedom of choice. Meanwhile, some limitations are needed to be established since the user has practically no architectural experience. This can be achieved by through examination of the implementation of constraints in other fields and contrasting this with the adoption of them in the building industry. Therefore, it is intended to use a verification system which is useful in relation to mass customization while performing constraints in real time.

In mathematics, constraint satisfaction problem (CSP) is a general problem defined as a set of variables that can take values from a finite and discrete domain and a set of constraints. Constraint propagation is another method used for such problems to make a given problem simpler to solve. Solving problems on these constraints is the process of communicating with the domain reduction of a decision variable, which could not be part of any solution to all of the constraints that are stated over this variable. While observing a design process, it can be seen that a number of constraints exists: limitations or restrictions for what can or cannot be done in the design process, and for what the design should fulfill. Each constraint defines a subset of the set of all possible designs in which it is satisfied. When several constraints are specified, the outcome is the possibilities within the intersection of all the intended subsets. This intersection becomes smaller as more constraints are added. The more values defined in a state, the more specific the design is. Ultimately, the meta-goal of design can be described as a process of transforming such constraints into design descriptions, using constraints in both a generative manner as well as in an evaluative manner.

Some examples of constraints are as follows:

- The height of the wall must be between 2 and 2.6 m.
- Windows with metal frames must have a profile thickness of at least 30mm.
- The material of floor of bathrooms must be ceramic, marble, laminate or vinyl.

Architecture involves a large number of rules and constraints, as stated above. When such a constraint-based system is being established, clear and concise communication should be achieved among related professions and the users. Most commonly design process commences with client’s submittal of requirements and budget to the architect. However, additional specification can be obtained from the dialogue between architect and client in order to specify complete design goals. Thus, all the design stakeholders should contribute to the process from the beginning. In the proposed system, the architect will do the base design as usual and specify a set of parametric constraints, rules and relationships through his intentions, which non-professional users cannot manipulate. Prospective residents, on the other hand, will see an interface viewing the results of their preferences and tools for generating house designs enabling them to decide and change the parameters through their preferences.

This thesis examines this compelling issue by using constraint checking method in the building industry. There are two alternatives of finding solutions; first one is taking the constraints as an input and trying to find an appropriate design. Second one is making the design and then checking. These checks could be done manually, but due to a large number of design drawings and constraints this would be exceedingly labor-intensive. Finding a method of automating this checking process would greatly benefit this phase. Offering suggestions, the system will not only support but also check preferences of users while evaluating the design. The result is a series of algorithms that make design of houses a customized process, reducing costs traditionally associated with custom design and increasing quality.

Both the architect and the user cannot foresee the end result of the process before entering into it. In this case, it will be more accurate to establish a system that conducts a dialogue with the user, generates a number of alternatives and visualizes them with their pros and cons. For this purpose, a two-stage model is developed considering the parametric constraints, rules and relationships specified by the design stakeholders. In the first stage, external inputs such as social structure, user profile, level of income, physical environment etc. are gathered in order to create a base for the design itself. In this way, main skeleton, footprint and core part of the building will be specified. The following stage is where a user makes preferences using a multiple-choice interface. Design gets more and more specific in accordance with the user's family structure, socio-economic level, etc. as well as establishing guidelines for the next step. After the best possible option is chosen from the variety of existing options, the user can manipulate the design directly within the pre-defined constraints in the next step. Additionally, the cost estimate will be monitorable as an additional value which enables the user to alter his/her preferences by simply following it.

In recent years, computer aided drafting has been largely replaced by Building Information Modelling-based alternatives. Although not strictly speaking a necessity for using constraints, Building Information Modelling allows automated constraint checking, which is much simpler. Effective software such as Autodesk's Revit presents an interactive environment where an architect can easily attach constraints and lock elements to establish relationships. For example, the dimension tool is used to create a sequential multi-segmented dimension for the gridline. By clicking the lock icon, a constraint, which inhibited the movement of the wall, is created. Schedules are another way of representing a data in order to quantify and analyze the components and materials used in a project. This data may include dimensional information, location information, descriptive information, cost information.

The thesis focuses on the study of an approach in architecture where users modify the design themselves and their designs are checked automatically for design constraints which is considered to be the key for achieving mass customization in architecture. This way, an infinite number of solutions, which can be manufactured in accordance with user requests, will be eliminated. Also the architect will naturally have a certain amount of control over the result by making the base design and determining the constraints. Most importantly, this approach ensures that the social housing residents' needs and requests are considered in design and that they achieve a much greater living standard without any cost increase.

KISITLARLA TANIMLANAN MİMARLIK: KİTLESEL ÖZELLEŞTİRME ODAKLI KONUT TASARIMI

ÖZET

Endüstri Devrimi'nin tetiklemesiyle birlikte, artan talebe cevap verebilmek, hızlı bir biçimde ve çok sayıda ürün ortaya çıkarabilmek amacıyla kitlesel üretime (mass production) başvurulmuştur. Mevcut teknolojiden yararlanılarak büyük hacimlerde standartlaşmış malların üretimini tarif eden bu kavram, zamanla endüstrilerde yenilikçi bir yaklaşım olarak kabul görmüş ve büyük ölçekli üretim ekonomilerine ortam hazırlamıştır. Kişiye özel üretimde, kullanıcının ihtiyaçlarına, tercihlerine ve fiziksel özelliklerine cevap verebilen, aynı zamanda yoğun emeğin ve zamanın harcandığı ve dolayısıyla maliyetlerin yükseldiği bir kurgu vardır. Bundan farklı olarak, kitlesel üretimin kapsamı bir yığın biçiminde üretilmesi gereken gıda, kimyasal, vb. maddelerden, bilgisayar, otomobil gibi ayrı ayrı işlenebilen ürünlere dek uzanmaktadır. Bu sistemdeki temel amaç, üretim hacmini genişleterek maliyetleri en düşük seviyeye indirmektir. Sonuçta elde edilen ürünler oldukça sıradan olmasına rağmen, kitlesel üretim, aynı anda çok sayıda ürün elde etmeye olanak sağladığından ve kişiye özel üretilen ürünlere kıyasla ekonomik olduğundan dolayı, uzun süre tercih edilen bir yöntem olmuştur.

Günümüz iletişim ve teknolojisinin üretim sistemlerine olan yansıması, kişiye özel üretimin (tailored production), aynı zamanda endüstriyel hız ve düşük maliyeti sağlayacak biçimde evrilebileceğini göstermiştir. Kitlesel özelleştirme (mass customization) adı verilen bu kavramdaki anahtar nokta, bunu bir süreç olarak görmek ve bu süreci kullanıcı ihtiyaçları doğrultusunda yeniden düzenleyebilmektir. Birçok endüstri, bu özgün harekete uyum gösterebilmek adına üretim hattını bu doğrultuda değiştirmiş ve geliştirmiştir. Amaç, organizasyonun mevcut imkanlarını bilgisayar destekli tasarım ve üretim sistemlerinin de kullanımıyla geliştirerek, yüksek standartlarda ürünler ortaya çıkarmaktır. Böylelikle kullanıcının kendi istekleri doğrultusunda ürünler elde etmesi de sağlanmış olur.

Bu sistem uzun zamandır otomotiv, bilgisayar, giyim gibi pek çok hızlı tüketim endüstrisi tarafından farklı yöntemlerle kullanılmaktadır. Örneğin, önemli bilgisayar üreticilerinden Dell, müşterilerinin bazı donanım ve yazılım özelliklerini belirlemesine ve isteklerine uygun bilgisayarları internet ortamından sipariş etmesine olanak sağlamaktadır. Bu sistemde kullanıcı, basit bir arayüz kullanarak bazı tercihler yapmakta ve satın alacağı parçaları belirlemektedir. Daha sonra bu parçalar bir kontrol listesi ile bir araya getirilir. Eşzamanlı olarak maliyet değişimini de takip edebilen müşteri, bir anlamda Henry Ford'un metodunu internet üzerinden gerçekleştirmiş olur: emek sürecinin pazarlanarak kullanıcı isteği olarak satılması. Bir diğer örnek ise

Levi's-ın New York'ta başlattığı "Made to Order Jeans" adındaki uygulamasıdır. Buraya gelen müşteri mağazada ölçülerini vermekte, kumaş, renk gibi tercihlerini belirlemekte ve ona uygun olarak hazırlanan ürünü adresinden teslim almaktadır. Hızlı tüketim endüstrilerinin aksine, kitlesel özelleştirme, mimarlık alanında çok sınırlı noktalarda karşılık bulabilmiştir.

II. Dünya Savaşı'ndan itibaren pek çok ülkede kentleşmeye bağlı olarak hızlı konut üretimi söz konusu olmuştur. Ancak benzer ihtiyaç Türkiye'de, özellikle İstanbul'da, niteliksiz konut üretimine ve çarpık kentleşmeye sebebiyet vermiştir. Yani kentlerdeki konut stoku nüfus artışı karşısında yetersiz kalmış ve bu da gecekondulaşmayı doğurmuştur. Tam da bu noktada hükümet, konut üretimini rasyonelleştirmek adına 80'li yılların başında TOKİ'yi (Toplu Konut İdaresi) kurmuştur. Kurumun amacı, dar ve orta gelirli vatandaşların nitelikli konut ihtiyacını, düşük maliyetlerle karşılamaktır. Ancak zamanla çok sayıda konut üretebilmek adına bu amaçtan uzaklaşılarak kullanıcının ihtiyaçları ve yaşam tarzları göz ardı edilmiş, bu da kişilerin konforsuz hissetmesine ve ötekileşmesine yol açmıştır (değişmeyen plan tipleri, yapısal standartlaşma ve tekrar eden tipolojiler). Özel sektörün dahil olduğu konut üretimlerinde de benzer bir durum söz konusu olsa dahi, özellikle sosyal konut kullanıcıları için kitlesel özelleştirme, seçme şansını sıfıra indirdiği için, çok daha kritik bir noktadadır. Halbuki konut, kişinin karakterini yansıtan ve bu bağlamda kendini tamamıyla rahat hissetmesi gereken bir yerdir.

Bu doğrultuda, kitlesel özelleştirmenin konut üretimi için kullanılması oldukça önemlidir. Ancak mimarlık, yapısı gereği karmaşık bir sürece sahip olduğundan, kitlesel özelleştirmeyi uygulamak diğer endüstrilere kıyasla daha farklı bir yaklaşım gerektirmektedir. Örneğin, bir ayakkabı markası kullanıcıya çeşitli alternatifler ve değiştirilebilir bileşenler sunarken, mimari bu anlamda daha farklı bir yerde durmaktadır. Modern çağın en önemli bileşenlerinden biri haline gelen iletişimin boyutu, algılamayı, tartışmayı, keşfetmeyi ve tüm detayları önceden çözmeyi sağlayabilmektedir. Dolayısıyla, günümüzde tüm aktörlerin kullanımına ve iletişimine olanak sağlayacak bir sistem geliştirmek, dijital tasarım araçları, gelişmiş kullanıcı ara yüzleri ve otomasyon sistemleri ile mümkün olabilmektedir. Bu bağlamda, tez kapsamında, kullanıcının ve diğer aktörlerin merkeze alındığı ve dijital araçların/ara yüzlerin kullanıldığı bir sistem önerilmektedir. Bu sistem teknik anlamda mimarın geleneksel sürecine paralel bir yaklaşım sergiler. Girdiler ve aktörler aynı olmasına rağmen, bu aktörlerin sürece dahil oldukları noktalar ve bazı yöntemler farklılık göstermektedir. İkisi arasındaki en önemli fark, kullanıcının en başından itibaren süreçte bulunması ve özelleştirmenin tam da o aşamada başlamış olmasıdır. Ancak, sürece dahil olacak olan kişilerin meslek profesyoneli olmadığını varsayarsak, belli noktalarda kısıtlamalar getirmek ve yapacakları tercihlerin belirli bir çerçevede kalmasını sağlamak gerekmektedir. Böylelikle mimar da sonuçta ortaya çıkacak olan tasarımda problemler çıkmayacağını ve onun oluşturduğu temel tasarımın bir uzantısı olduğunu bilecektir.

Kısıtların (constraints) kullanımı matematikte, oyunlarda, bulmacalarda ve pek çok mühendislik alanında geniş yer bulmaktadır. Bunun yanı sıra pratik anlamda mimaride de teknik gereklilikler, yönetmelikler, mimarın ve diğer meslek profesyonellerinin kararları, işverenin talepleri gibi pek çok kısıt mevcuttur. Bunların her birini tek tek kontrol etmek zaman kaybına yol açacağından, bir doğrulama sistemi (verification system) oluşturmak gerekmektedir. Aynı zamanda, böylesine kısıt- tabanlı bir sistem geliştirirken, sisteme dahil olan aktörler arasında etkin bir diyalog kurulması da en önemli noktalardan biridir. Doğru uygulandığında, mimarın temel anlamda tasarımı yaptığı, belli parametrik kısıtları, kuralları ve ilişkileri kendi niyetleri doğrultusunda işlediği, dolayısıyla kullanıcıyı belli sınırlar dahiline tuttuğu bir sistem ortaya çıkabilecektir. Dolayısıyla kullanıcılar daha evlerine girmeden kendi ihtiyaç ve talepleri doğrultusunda belli tercihler yapabilecek, bütçelerine göre bu tercihleri eşzamanlı olarak değiştirebileceklerdir.

Kullanıcı da mimar da verilen programın neticesinde nasıl bir sonuç çıkacağını sürecin içerisine girmeden öngöremeyebilir. Bu durumda, kullanıcıyı da sürece dahil eden böylesine bir sistem oluşturulurken, bir problem çözme aracı oluşturmak yerine, kullanıcıyla diyaloğa giren, alternatifler üreten ve hatta alternatiflerin bir takım mimari özelliklerini, artılarını eksilerini görselleştiren bir şekilde tasarlanması daha doğru olacaktır. Nasıl ki mimar kendisine verilen programa göre bir tasarım yaparken eskizler, maketler ve modeller üzerinden yaptığı değişiklikleri ve doğuracağı sonuçları anlayıp müdahale ediyor ve bu şekilde bir sonuca ulaşıyor ise, evini belirli isteklere göre özelleştirmek isteyen kişi de, belirli ölçüde böyle bir sürece dahil edilebilmelidir.

Bu amaçla geliştirilen sistemde, tıpkı geleneksel süreçte olduğu gibi, ilk önce bazı çevresel analizlerle süreç başlamaktadır. İlk aşama, potansiyel kullanıcı parametreleri ile kurgusal anlamda yapılan bir ön özelleştirmedir (pre-customization). Bu aşamada, kentsel ölçekte 500 m.'lik çeperdeki veriler (ör. sosyal strüktür, kullanıcı profili, gelir düzeyi, fiziksel çevre, vb.) tasarıma temel bilgiyi sağlayacak altlığı hazırlayacaktır. Örneğin iş merkezlerinin yoğun olduğu yerlerde, taban alanı, ek fonksiyonlar, güvenlik talebi, sosyalleşme alanı, vs. ihtiyaçlar ona göre şekillenebilecektir. Bu aşama sonunda, bulunduğu bölgenin verilerine göre şekillenen bina iskeleti ve çekirdek elde edilmiş olacaktır.

İkinci aşamada gerçek kullanıcılar devreye girecek ve tıpkı Volkswagen in yaptığı gibi, seçenekler sunan bir ara yüzü ile belli tercihler yapacaktır. Bu tercihler, yönelim, kat düzeyi (level), oda sayısı, malzeme vb. gibi asıl konut oluşumuna yön verecek olan verilerdir. Bu aşamada kullanıcıya sağlanan seçenekler, sürecin başında işveren ve mimarın süzgecinden geçmiş olacak ve konut, gerçek kullanıcı parametreleri ile daha belirgin hale gelecektir. İlk aşamanın devamı olarak, kullanıcının yaptığı tercihler doğrultusunda örnek bir daire modeli belirlenecektir. Bu daire modeli hem üç boyutta, hem de iki boyutta gözlenebilir ve eş zamanlı düzenlenebilir olacaktır. Aynı zamanda yaptığı seçimlerin listesi ve buna bağlı olarak maliyet tahmini de belirleneceğinden, kontrollü bir şekilde tercihlerini gözlemleyebilecektir.

Bu doğrultuda, bir odayı eksiltebildiği, duvarların yerini oynatabildiği, döşeme malzemesini değiştirebildiği bir sürece giren kullanıcı, mimarın daha önceden belirlemiş olduğu kısıtlar dahilinde tercihlerini yapabilecektir. Örneğin ilk aşamada orta düzey malzeme segmentini seçen kişi, ikinci aşamada malzeme seçerken sistem ona granit seçtirmeyecek, ya da bir odayı ikiye bölmek isteyen kişi duvarı 45 derecelik açıyla ekleyemeyecektir. (Süreçte mimar daha çok geometrik, strüktürel, malzeme bazlı kısıtlar entegre ederken, işveren de bütçe ile ilgili kısıtları belirliyor olabilir.) Bu değişikliklerden sonra örneğin bütçedeki artış, onu gerekirse geri döndürüp, önceki tercihlerini de optimize ettirebilir. Dolayısıyla bu sistemde kullanıcı, bir alt yüklenici gibi sürece dahil olabilecektir.

Tasarım aşamasında kısıtları destekleyecek şekilde üretilmiş olan ilk uygulama Autodesk'in Revit adlı BIM programıdır. Bu program özellikle mimarın bazı kısıtlar (constraint) belirleyebilmesine olanak sağlayacak şekilde interaktif bir ortam sunar. Örneğin, bir duvarın yeri kilitlenebilir ölçü ile (locked-dimension) belirlendiyse, bu bir geometrik kısıt oluşturur, dolayısıyla kilit açılmadığı yani kısıt kaldırılmadığı takdirde duvarın yeri oynatılamaz. Aynı şekilde mimar ardışık ölçüler belirleyip, bu ölçülerin birbirine eşit olmasını isterse, eşitlik kısıtı (equality constraint) yaratabilir. Şayet pencereler duvara eşitlik kısıtı kullanılarak yerleştirildiyse, toplam ölçü değişse de, pencerelerin arasındaki mesafe eşit kalmaya devam edecektir. Kısıtların kullanımı sistemde oldukça güçlü olduğundan, üç boyutlu modeldeki istenmeyen çakışmalar için kontrol sağlanabilmektedir. Eğer doğru bir şekilde uygulanırsa, mimar esnek bir bina modeli elde edebilirken, değişiklikler de otomatik bir şekilde tüm elemanlara yayılarak (propagation) tüm sistemde belli sınırlar içinde kalır. Geometrik kısıtların yanında, program dolaylı olarak bazı maliyet ve malzeme kısıtlamaları da sağlayabilmektedir. Bunu yaparken bazı değerleri hesaplayarak, mimari öğelerin özelliklerini bu çizelgelerde listeler. Mimarın, işverenin ya da kullanıcının yaptığı bir değişiklik eş zamanlı olarak bu listelere yansıyacağından, belli bir malzemenin kullanıldığı alanlar toplanabilir ya da bir mimari öğenin sayısı belirlenebilir. Program bu değerleri çizelgelerde arşivlemekte ve bu veriler maliyet kontrolü ya da tahmini sağlamada özellikle işveren için oldukça faydalı olabilmektedir.

Böylesine bir sistem kurgulanırken, hipotezi geliştirmesi adına bir prototip üzerinde çalışılmıştır. Burada binanın düşey sirkülasyonu ya da mekanik şaftı gibi sabit alanlar belirlendikten sonra, kullanıcı kısıtları gözetilerek kendi isteklerine göre odaların yerlerini değiştirebilecek, banyoyu yatak odasının yanına alabilecek, hatta döşeme malzemesini belirleyebilecektir. Örneğin; tek yaşayan kişinin bir odayı küçülterek giyinme odası yaptığı ve yaşama alanını hem uyuduğu hem de ders çalıştığı alan olarak kullandığı bir daire ortaya çıkabilirken, diğer aile üç odayı da neredeyse eşit büyüklüklere ayırıp, her çocuğu için ayrı odalar sağlayabilir. Böylelikle kişilerin yaşam tarzlarına ve aile yapılarına göre kendi tercihlerini yapabildikleri ve bunu yaparken eşzamanlı olarak yaptıkları değişiklikleri gözledikleri, maliyet kontrolü yapabildikleri bir sürece girerler. Bu sürecin sonunda mimarın ve işverenin kontrolünde özelleşmiş konutlar kitlesel üretimin sunduğu efektif üretim tekniği gözetilerek ortaya çıkmış olur.

En basit seviyede düşünürsek, bunun günlük yasam pratikleriyle örtüşen bir takım standartlarını da bulmak mümkündür. Örneğin; kişi 3+1, 2+1 gibi zamanla ortaya çıkmış kriterleri değerlendirip ev almaktadır. Isıtma tipinin seçilebildiği, otoparklı ya da havuzlu olup olmaması seçenekleri gibi kişiye özel durumlar bir şekilde standarta dönüşmektedir. Kullanıcıların yapacakları özelleştirme de herkesin ortak paydada iletişim kurabileceği özelliklere dönüşebilir. Yani özetle ortalama bir kullanıcının yapacağı özelleştirme, daha birçok ortalama kullanıcı tarafından okunup anlaşılabilir ve daha sonra bunlar ortak bir sistemde toplanabilir.

Sonuç olarak tez kapsamında, kısıtların mimarideki kullanımı araştırılmış ve sonunda örek bir model hazırlanmıştır. Önerilen süreçte mimar anahtar bir role sahiptir ve sisteme kısıtlarını kolayca entegre edebilmesi, araştırmanın en önemli hususlardandır. Eğer bu kısıtları tasarıma entegre etmek elverişsiz hale gelirse, mimar kısıt-tabanlı (constraint-based) bir tasarıma yönelmeyebilir. Sonuç olarak, bu metodun herhangi var olan bir modelin yerine geçmesi yerine, mimarın, sürecine kısmen dahil edebileceği bir yaklaşım sunması amaçlanmıştır.

1. INTRODUCTION

When key ways of production had shifted from fields to factories in industrial age, implementation of mass production was a significant innovation to design methods. This approach aimed production of simplest designs in large quantities for significantly lower costs. Development of a machine-tool based industry, or production of machines to make machines, paced up mass production in all industries and enabled the producer to mass produce a certain item for lower costs with less amount of labor work. Nevertheless, this kind of production rapidly increased the supply of products from a limited range which in turn cut short of the choices available to the individuals.

For residential areas, economies dictate that houses are as much identical as possible results in a homogeneous urban setting and as a result do not fit their occupants in ideal ways. A similar case was set forth by a well-known quote from Henry Ford about the Model T, which has been an affordable automobile for the general public: “Any customer can have a car painted any color that he wants — so long as it is black” (Ford & Crowther, 1922). During those years, when Henry Ford was still experimenting with the assembly line, the statement kept its validity as only fast-drying black paint allowed for "full-speed" assembly for lower costs. The exact opposite of this spectrum is customization, where each product is unique and produced according to a variety of different specifications. In this case, costs are typically higher than those of mass production as the lack of repetition does not allow standardization.

1.1 Motivation

Over the past century, several industries have shown that high volume production can allow for individual choice in another approach called mass customization (van den Thillart, 2004; Huang and Krawczyk, 2007). With the increasing proliferation of digital technologies in design and production systems, it is now possible to achieve tailor-made quality at an industrialized speed and low-cost. Computer aided design and manufacturing will be two most important pillars to achieve affordable costs of mass production while offering satisfaction and a high living standard, responding to user needs. It is projected that just as mass production was crucial for manufacturing in the 20th century, mass customization will be the key to economic growth in the 21st century.

Historically, a common example for an industry in which mass customization is being implemented is personal computers. Many computer makers have allowed customers to specify hardware and software to be used in the making of their personal computers and even devised the system from scratch. Customers are allowed to assemble their personal computers as per their choices that are submitted via an internet checklist. Users then happened to be doing Henry Ford's assembly work for free: a labor process marketed and sold as consumer choice (Hogge, n.d). Another example is the Nike campaign in which Nike offered an "iD Lab" in downtown Manhattan to allow a small range of elite customers to personalize their shoes [1]. These have been limited attempts but have transformed into a new factory model where industrial production is a made-to-order tailoring process.

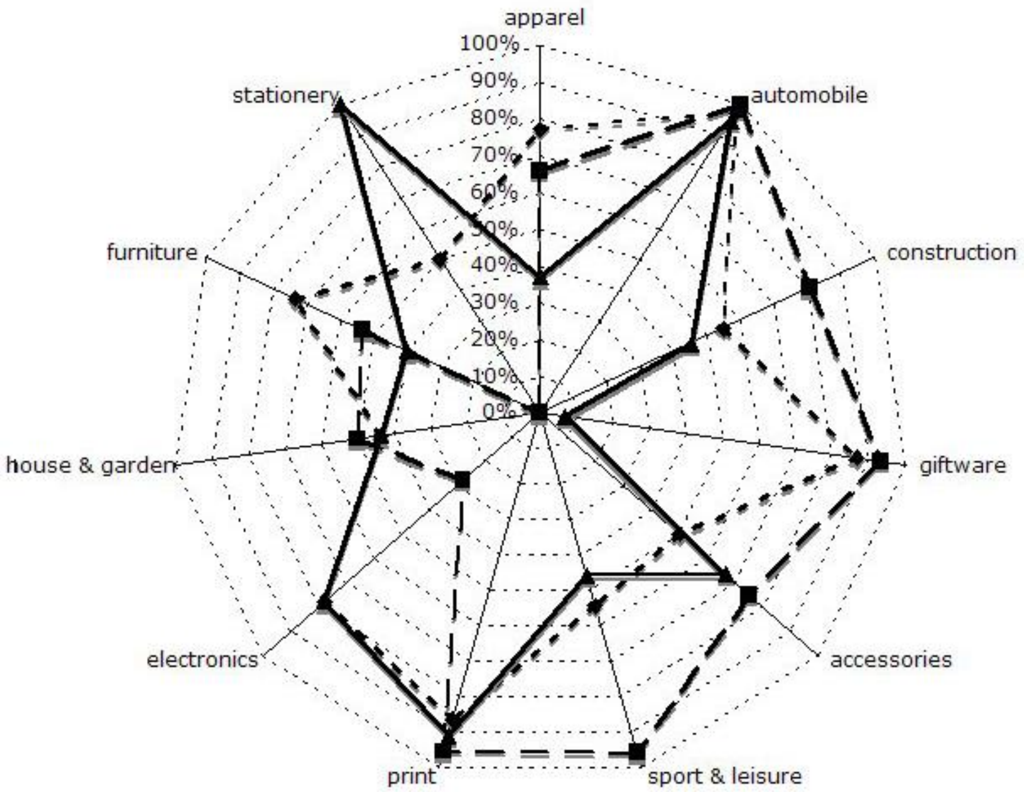


Figure 1.1 : Levels of MC in Certain Industries. [2]

The idea of being able to consider customer preferences has long fascinated architects, designers and engineers. Since the approach offers a customer to decide the exact specification of a product or service at or before the time of purchase. Additionally, customers purchasing that product or service are offered a price close to their mass produced alternatives while each are unique in their individual manifestation. Before the invention of computer aided design, this idea might have been thought as impracticable. Yet, Mass Customization can be achieved through Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) systems, which allow for more flexible output with little or no additional variable costs.

In the immediate future, people will encounter some user interfaces especially in their houses such as touchscreens, incorporated in for example, bathroom mirrors, tables or windows of a living room. This interactive environment will make computing and communication as a natural part of our lives. A recent example is an interactive wall installation that consists of 7 vertical fins and interacts with its surroundings through detecting motion, change in light and sound. Behavior of these modalities and the software behind it, were designed by Kas Oosterhuis and Chris Kievid, members of the Hyperbody Team.

Figure 1.2: Model of a wall that interacts with its surroundings designed by the Hyperbody Team in TuDelft. [3, 4, 5]

When one approaches one of the 7 fins in the installation, that fin retracts and takes a hollow form. Additionally, it can emit sound through an internal speaker and light through a pattern of LEDs underneath its “skin” [4].

What is not so apparent at the first glance is that all the nodes would interact with each other in a swarm-like manner. This behavior mimics a natural phenomenon called spontaneous synchronous order which is parallel to movements of creatures such as birds, fireflies and fish that manage to synchronize and act as a unit- when no one is giving orders [4]. Thus, just as there are human-object or human-architecture interactions, creating such a user-driven design system should not be an illusion or an unreachable state for an architect or a client.

1.2 Hypothesis

The industrialized method of building that has commonly been practiced since World War II, does not leave much room for individual choice especially for the design of residential areas (Niemeijer, 2011). In Turkey, the process of fast urbanization in larger metropolitan areas and the parallel growth of population raised the requirement for industrialization of housing. Turkish government responded to this requirement by asserting rapid housing production systems and policies in order to produce more houses. Current system is making use of rigid plan types, constructional standardization and repetitive typology while neglecting different characteristics and needs of the occupants. As such, customization is much needed to improve the overall quality of mass-produced social housings.

The building industry, however, has a different production line than those of personal computers, shoes or cars. To begin with, size, time frame, work schedule and costs distinguish the building industry from the rest. Considerable differences in said areas in addition to much more complicated and detailed specifications that the building industry involves by nature limit flexibility for customization. Buildings are realized through onsite project work rather than through offsite production. Therefore, the field of work comprises of multiple entities from various professions with contradictory needs. Furthermore, any approach to mass customization in architecture demands active connection with the user as housing is not just an expensive product but a home, a place where the habitant should feel a complete comfort.

In most cases, though, the amount of flexibility is still limited, since the two traditional ways of offering mass customized housing, either as a fully customized design or as a choice out of predesigned alternatives, result in a trade-off between the freedom offered and the amount of time and cost required. However, for social housing residents, even these two alternatives are not valid in some cases. For axample, in 2004, Ayazma and Sulukule neigbourhoods were declared as urban transformation areas, and the residents were forced to evacuate their neigbourhood and move another residential area, executed by the government.

The past few decades, in particular, have seen an ever-increasing adoption of mass customization in the building industry and a need for technical support for the inclusion of users' decisions in design. I propose that it can be practically achieved through automated production systems, digital design tools and advanced user interfaces. Communication tools and Building Information Models already technically allow architects and their collaborators to conceive, discuss, explore, and understand every detail before production. A practical and accessible Building Information Modelling based system that includes the user and the client can be the solution to the achievement of this mass customization approach (Kieran & Timberlake, 2004).

1.3 Methodology

Motivation behind this study is to address the need to implement mass customization techniques to the architectural discourse. Accordingly, an approach is presented in which users are free to make modifications to the design themselves in the case of having only a user-driven design corresponds to a mass customization entirely. On the other hand, this introduces a number of challenges such as the involvement of non-expert users in the production process. For this reason, it is important to provide a detailed model and specify constraints while supporting users by offering suggestions and avoid them to make design mistakes.

In this proposed method of housing design, the architect creates a master design, as usual. In addition to that, however, s/he also specifies a series of constraints indicating what he will and will not allow the user to change. For this aim, a prototypical tool is developed for design case that offers an effective access to computational building modelling and in turn facilitates this new approach to mass customized buildings.

Per this methodology, instead of taking the constraints as an input and trying to find an appropriate design (constraint solving), it is preferred to use a verification system (constraint checking) in order to make valid designs. As the designer has the advantage of professional experience, it will take him/her less time to converge on a good (though not necessarily optimal) design than by using the constraint solving method. For this aim, constraint checking is tested as a technically and conceptually viable method for this inclusion and the broader impact of the proposed model to the present construction methods is discussed. A framework is developed for implementing mass customization in architectural practice with focus on housing design.

In order to make the adoption of mass customization in the building industry more feasible from a design perspective, it is preferable to use a representation that allows for a more high-level view of the design than the traditional collection of two-dimensional lines. The proposed model uses Revit, a constraint-based Building Information Modeling (BIM) software and creates a parametric three-dimensional model that includes both the geometric and non-geometric design and construction information. Revit has two key characteristics, such as all relationships between components, views, and annotations are captured by the model, and the software uses parametric components which are created using a graphical "family editor" rather than a programming language [6]. It is easier to manipulate the design for the user/the client and the architect using a visual object generation tool where constraint-based design yields to inclusive design.

I explore and accumulate the knowledge necessary for a system that can intelligently support non-designers in the process of creating and modifying architectural designs. The architect still has some control over the result in proposing the master design and determining the constraints. The system provides the user an architecturally proper design customization according to his/her preferences. Thus, user needs and requests will be taken into account in design, resulting in the residents' much greater living standard without any price increase.

1.4 Thesis Overview

As covered in the previous sections, allowing people to choose from a set of alternatives quickly becomes impractical due to the amount of total variants that have to be designed. A one-on-one meeting with the architect may not be sufficient as the meeting itself requires the allocation of significant amount of time, especially for the social housings. In that design session, all clients can become prohibitive. A third alternative that will be explored in this thesis, is to allow people to modify the design themselves. This way, buyers are able to design their house exactly the way they want it to be. Chapter 2 discusses the use of mass customization in both the building industry and other industries and sets forth that there are still many opportunities for increased adoption of mass customization in the building industry.

Naturally, there are limitations to the adjustments that customers can make, as it is important to not to overwhelm buyers with more options than they can handle in a time efficient manner. Allowing non-experts to design a house introduces a set of new problems such as, being unaware of building regulations that would potentially lead the users to create inappropriate designs. Therefore, all the buyers' designs will have to be checked to see if they comply with both building regulations and the architect's vision or not. Chapter 3 investigates ways to implement constraints in various industries, and explains the way constraints may be used in this research.

For the sake of time efficiency, the task of design checking should not be labor-intensive. Ideally, a large part of design verification could be done by a computer. Chapter 4 describes the developed prototype, testing the viability of constraint-driven design in the building industry and one method of constraint entry using a Building Information Modelling system, such as Revit. Finally, chapter 5 concludes the thesis with a detailed evaluation and discussion as well as recommendations for further studies.

2. MASS CUSTOMIZATION

2.1 Production for Individuals and for the Masses

Ever since the distribution of labor started to shape our society and people began to focus on tasks they were particularly good at, craftsmanship has become one of the main forces driving modern economy. (Kaplan & Haenlein, 2006). This specialization, as such in tailoring, blacksmithing, and carpentry, provided advantages on goods that are tailored exactly for their customer's needs. By simply purchasing these items from such professions gives people the opportunity for getting appropriate size, taste, style, need, and expression. However, as mentioned above, one-of-a-kind production often resulted in a price increase because of the time spent and high degree of manual work. In time, people would prefer less customization for lower prices, instead of having the tailor made quality.

During the era of Industrial Revolution in 20th century, the call for rapid and efficient production triggered the rise of mass producers. Afterwards, Henry Ford introduced the first moving assembly line in 1913 aimed at "put[ing] the world on wheels" (Nabli, 2008) and Taylor (1911) published a proposal dealing with questions of coordination and control. In order to reduce time and minimize cost, this period was shaped by an increasing fragmentation of tasks and division of labor. Even though the outcome was simple and ordinary, mass production efficiency could be achieved through using these methods.

Figure 2.1 : 'Model T Ford' produced by Henry Ford's Ford Motor Company from February 30, 1908 to May 27, 1927.

2.2 Customizing Production

Around the mid-1950s, the desire for customized products led to the concept of market segmentation, in which customers with similar preferences were grouped according to the basic needs of the average customers (Smith, 1956). This differentiation in the manufacturing process was the first attempt to the mass customization.

Customization was even possible without sacrificing the advantages of cost-efficient manufacturing due to large segments. However, in time, mass markets evolved through recognizing each customer as an individual while provided them the tailor-made quality. Toffler (1970) questioned these two unique strategies, and Davis (1987) introduced the term mass customization to describe the oxymoron of mass producing customized products.

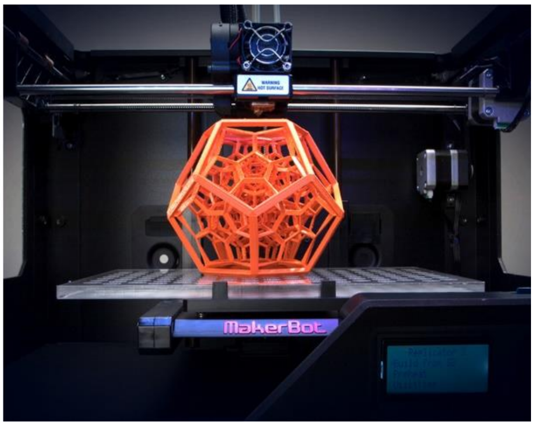


Figure 2.2 : Present Day Production Systems: Robotics (Left) and 3D Printers (Right).

Certainly the basic idea behind this approach is not revolutionary, however, new manufacturing techniques and advances in information and communication technology play a crucial role in this type of production (Kaplan & Haenlein, 2006). The internet, for example, has made mass customization a viable option for a broad range of products in order to conduct a dialogue between the customer and the producer. Therefore, shift to the digital economy, where all the information and processes are digitalized and shared all over the world, is a precondition of mass customization. Additionally, the customer's awareness and perception of mass customization is mentioned as another prerequisite of the concept (Davis, 1989).

2.3 Literature Review

In this chapter, some mass customization methods used in various industries are discussed. Building Information Models are also covered, due to their use in mass customization in the building industry. And finally, a method for adopting mass customization in the housing industry is developed.

2.3.1 Definitions

In particular, it is essential to sort definitions by researchers across a broad range of disciplines and their differentiated statements about the concept mass customization before developing a definition for architecture. In the last several decades, after the fordist period, most industries and academia have put a lot of effort in formalizing and characterizing this hybrid concept of mass customization.

In his book Future Perfect, Stanley Davis (1987) first coined the phrase -mass customization- to describe mass production implemented customized products aiming the tailor-made quality with the industrialized speed and cost effectiveness. According to him, mass customization simply takes advantage of latent capabilities. Entrepreneur and author Joseph Pine (1993) later expands this concept into design and production systems such as computer integrated design and manufacturing (CAD/CAM), and propagates the usage of computer and digital technologies to work with precision. He also categorizes mass customization as a combination of elements characteristic of both craft production and mass production. In Kieran and Timberlake's book, Refabricating Architecture (2004), the use of "information-based" design and production techniques are encouraged, already commonplace in other industries. Since, transformation of the traditional supply chain was essential for the customer point of intervention. It can be seen that some authors have defined mass customization as a concept applicable to products only. For example, von Hippel (1998) mentions that mass customization generally refers to the manufacturing of one-of-a-kind, 'custom' products. These 'mass customization' methods have enabled custom goods to be produced with near mass production efficiency (Franke & Piller, 2004). Correspondingly, for Ettlie and Ward (1997), mass customization means providing products that are created to the customers' specifications. One can also logically extend the concept of mass customization to the production of customized services. For Hart (1995), the practical definition of mass customization is the use of flexible processes and organizational structures to produce varied and often individually customized products and services. Similarly, Zipkin (2001) indicates the issue as a capability to offer individually tailored products or services on a large scale. In a different point of view, mass customization is not restricted to products and services. It also applies to customers and markets (Davis, 1994). McCarthy (2004) highlights that mass customization involves balancing operational drivers by defining it as "the capability to manufacture a relatively high volume of product options for a relatively large market, or collection of niche markets, that demands customization, without tradeoffs in cost, delivery and quality".

For some authors, such as Pine, Peppers and Rogers (1995), the definition is limited to the manufacturing of goods. Customization means manufacturing a product or delivering a service in response to a particular customer's needs. Mass customization means doing it in a cost-effective way, though. However, some other researchers also have used this concept to describe other value chain activities, such as distribution. According to Ahlstrom and Westbrook (1999), the definition is not limited only to the manufacturing of goods. It is a term first coined to describe a trend towards the production and distribution of individually customized goods and also for services for a mass market, or marketing. It is the practice of mass customization in which each element of the marketing is based on standard platforms or architecture. Several authors have included considerations of cost by saying "at the low cost of a standardized, mass production system" (Hart, 1995), or "with mass-production efficiency and cost" (Lee et al., 2000), on the other hand many others have not mentioned these characteristics.

"It can be seen that authors from different fields of study, such as innovation management (e.g., Franke and Piller, 2004; von Hippel, 2001), marketing (e.g., Kotler, 1989; Sheth, 1992), strategy research (e.g., Ettlie and Ward, 1997; Kotha, 1995), or public affairs (e.g., Collins and Butler, 2003)—understand the concept of mass customization in a similar way" (Kaplan & Haenlein, 2006). Otherwise, it is difficult to ensure everyone is referring to the same concept when using the same terminology.

In architecture, mass customization is a difficult approach since architecture has long been a service-oriented industry directed to the "market of one". The complexity of buildings and involvement of more and more specialized professions in the design and building process makes the implementation tackling. However, digital tools can be used in meaningful ways to enhance collaboration as easily as control. Indeed, the definition for architecture can be as follows:

Mass Customization is a sophisticated process and a strategic mechanism that requires both user and client involvement in the production process, because it is impossible to get a customized output without knowing the demand. Also, in order to reach the mass production efficiency, it is crucial to use digital design tools from the beginning of the process to prevent post-delivery remodeling, extra use of resources and time spent.

2.3.2 Classifications

There are many ways to classify mass customization into different types. This section contains five of the more commonly cited categorizations that lead to a more solid understanding of mass customization research.

2.3.2.1 Strategies of standardization and marketing

In "The Four Faces of Mass Customization", according to Gilmore and Pine (1997), there are four different types of mass customization: collaborative, adaptive, transparent, cosmetic.

In the case of adaptive customization, products are highly standardized and marketed as being customizable. An example would be a typical office furniture, such as chairs, monitors, even desks, which can be adjusted to accommodate the varying sizes and needs of the employee. Also, lightning companies produce special fixtures to be able to change the lux level that provides adjustable light control.

If a standardized product is marketed to a group of potential customers, this is called cosmetic customization. This kind of target audience, at whom a company's marketing is being directed, could be specified according to geography, demographics, socioeconomics, behavior, and psychology, etc. For example, people who live in areas that experience cold weather, or mountainous regions would be more interested in the winter apparel or equipment used for winter sports [7].

Transparent customization has an opposing direction to the cosmetic customization. Since it provides the individual customers with unique goods or services without letting them know that those products and services have been customized for them. For example, Coca Cola, a major soft drink company, sells its special concentrate to different corporate franchises around the world. The final ingredients added locally after the concentrate arrives at the bottling plant [8]. Thus, the flavors might vary in different countries with the same name and a customized product ended up marketed as standard.

In collaborative customization, the producers communicate with their customers. For custom-sized denims, women can walk into a Levi's store, get measured, and then order jeans tailored to fit their body types [9]. Also they have the opportunity to select the materials and create design details. The automobile industry operates on this basis too. This kind of customization is appropriate for businesses whose customers cannot easily articulate what they want and grow frustrated when forced to select from a plethora of options (Gilmore & Pine, 1997).

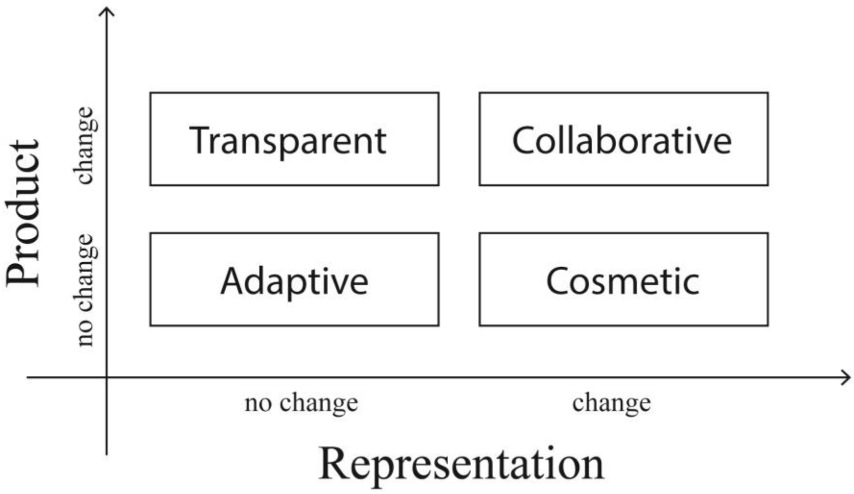


Table 2.1 : The Four Approaches to Mass Customization (Adapted from Gilmore & Pine, 1997).

2.3.2.2 Basis of modularity

A number of product design observers suggest that true mass customization requires modularity which is the key to achieve low cost customization and can impact different stages within the production cycle. Duray et al. (2000) categorize modular customization into six types by the value chain at which customization appears to take place. Common components used in component sharing modularity, such as different cars sharing the same chassis. In component-swapping modularity, modules can be selected from a list of options to be added on a standard base product. For example, in personal computers, CPU or hard drive can be replaced with different/other models.

Cut-to-fit modularity means that dimensions of a module can be changed to a certain extent, like eyeglasses, before combining with the rest of the product remains the same. Similar to component swapping, mix modularity combine the different parts of the product but losing their unique identity at the end. House paintings are a good example. In bus modularity, it is possible to add one or more modules to an existing base, such as track lighting. Section modularity, finally, focuses on putting the standard pieces together in a unique pattern, as in the Legos.

<table>
<tr><th></th><th></th><th colspan="4">Type of Modularity</th></tr>
<tr><th></th><th></th><th>Design</th><th>Fabrication</th><th>Assembly</th><th>Use</th></tr>
<tr><td rowspan="4">Point of Customer Involvement</td><td>Design</td><td colspan="2" rowspan="2">1
Fabricators</td><td colspan="2" rowspan="2">2
Involvers</td></tr>
<tr><td>Fabrication</td></tr>
<tr><td>Assembly</td><td colspan="2" rowspan="2">3
Modulizers</td><td colspan="2" rowspan="2">4
Assemblers</td></tr>
<tr><td>Use</td></tr>
</table>

Table 2.2 : Matrix Grouping of Mass Customization Configurations (Adapted from Duray et al., 2000).

2.3.2.3 Point of customer involvement

Piller and Tseng (2000) identified two dimensions of mass customization: soft customization and hard customization. In soft customization, customers does not involve in the manufacturing process and customization is actualizing outside of the company. The sub-categories of soft customization are: self-customization (creation of customizable products), point-of-delivery customization (customization of standard products at the point-of-delivery), and service customization (customization of services around standard products and services).

Hard customization, adversely, involves customer participation in the value chain. In this type of customization, every user can take their one-of-a-kind product on the shop floor. This approach has three sub-categories: customization standardization mix (either the first or the last activities of the value chain are customized within the factory, while keeping other activities standardized-garment customization), modular product architecture (production of customized products on the basis of modular building blocks, personal computers), and flexible customization (use of flexible manufacturing systems for the production of highly customized products without considerably affecting the cost position, bicycle industry).

Soft Customization	Hard Customization
Self Customization	Customization-Standardization Mix
Point-of-Delivery Customization	Modular Product Architectures
Service Customization	Flexible Customization

Table 2.3 : Soft and Hard Customization as a Major Dimension for the Classification of MC Approaches (Adapted from: Piller & Tseng, 2000).

2.3.2.4 From the operating processes of manufacturing

Another subdivision is given in “Customizing Customization” (Lampel & Mintzberg, 1996), where five types of mass customization are identified based on the moment at which the customer enters the production chain: pure standardization, segmented standardization, customized standardization, tailored customization and pure customization.

In pure standardization, the user does not enter into the production process. The only flexibility provided is that is inherent in the product, such as the adjustability of car seats, sports items, ladders, light fixtures, etc. In segmented standardization, the market is segmented and the client enters the production process in the distribution phase. Accordingly, Sony strikes a balance between standardization and adaptation. The basic machines are identical worldwide, while the keyboards and software are varied to suit local conditions. In customized standardization, the client is brought in one step earlier, in the assembly phase that the customer can assemble the product out of standardized components. Dell allows their customers to customize their software via internet, and then they deliver it within two or three weeks with additional cost and a little time extension. This kind of customization can be applied to a single product, but it is also possible to develop an entire product family in which all products share the same components. This is known as platform-based customization. (Du et al. 2001, Simpson

2004). Tailored customization involves the client from the fabrication phase onwards. An obvious example is a tailoring process of a suit that adapts to fit the customers' body sizes. A German-based company, Mass Couture, made this process available on the internet where the application takes your own measurements and fabric preferences. In pure customization, finally, the client is involved starting from the earliest phase, in which the product is designed. A good example is TaylorMade, a brand subsidiary of Adidas, that manufactures golf clubs, bags and accessories. Its most important feature is gathering your swing information and using it to determine the optimum combination of equipments to optimize the golfer's performance.

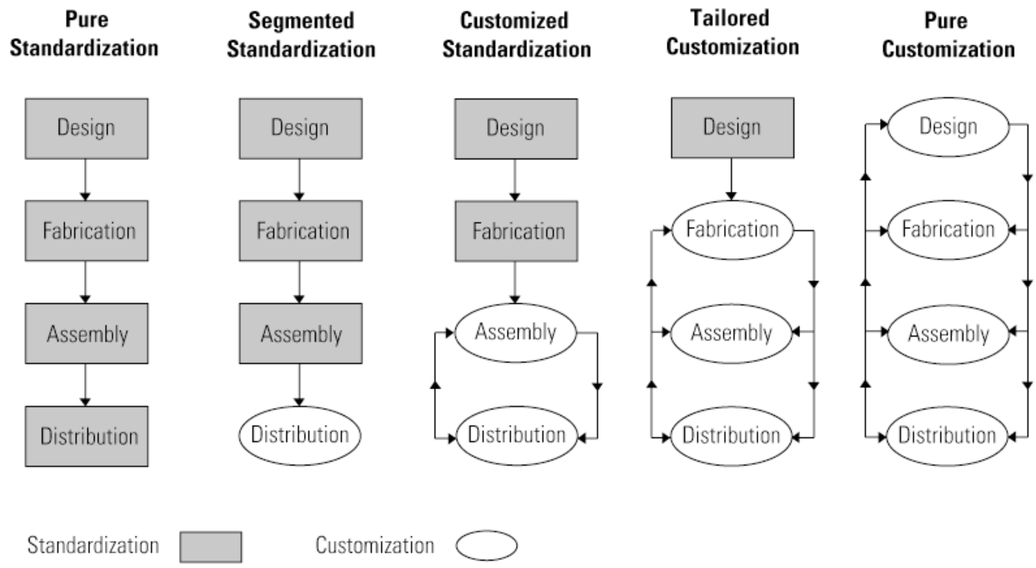


Figure 2.3 : A Continuum of Strategies for Mass Customization Application (Lampel & Mintzberg, 1996).

2.3.2.5 In the context of the automotive industry

Alford et al. (2000) identify three approaches to implement mass customization specifically in the context of the automotive industry: core, optional, and form customization. His examples are all based on the extent to which customers can influence the design from the value chain perspective.

In the core customization, customers have a lot of influence over the design. This type mostly occurs in the low-volume vehicle market. Optional customization allows customers to choose the right vehicle from a wide range of options. There is a large number of brands and each brand has several models already. Form customization allows changing standard parts or making enhancements to the actual vehicle through dealers or retailers as such in the satellite navigation systems or hub caps.

VALUE CHAIN

WHERE CUSTOMIZATION OCCURS	Customer	Distribution	Manufacturing	Design
Core Customization	Needs	Customized	Customized	Customized
Optional Customization	Needs	Customized	Customized	Standard
Form Customization	Needs	Customized	Standard	Standard

Table 2.4 : Classifications in the Context of Automotive Industry (Adapted from: Alford et al., 2000).

Therefore, definition and classification are essential preliminaries to analysis, since they help to ensure theories in order not to be mixed up in an affair. So, these classifications are crucial to deeply understand and analyze the different perspectives among functional disciplines.

2.4 Mass Customization in Architecture

When trying to introduce mass customization to the building industry, we can see that the scale of the projects is typically much larger than other industries. Also, there is a correlating increase in the amount of parties involved unlike fast moving consumer goods, computers or cars. In Kieran's words (2004), architecture is a custom-crafted industry that is static and depends on the ground and its properties rather than its scale, because there are ships bigger than three or four building together. In the scope of this thesis, it is important to deeply analyze the processes, materials and circumstances of mass customization experimented in the other industries, try to comprehend its extends before implementing mass customization and generating a new approach in the building industry. This approach can be traced in the works of well-known architects and researchers from the Modernist era such as Le Corbusier, Walter Gropius, and Frank Lloyd Wright, and in John Habraken's designs from the postwar era. Habraken is proceeded by others such as Duarte, Smithwich, and Plewe around the turn of the 21st century. What is common among these projects is the desire to devise a scheme that could be used to generate affordable mass housing, using industrialization for lowering the costs and trying to consider the needs and demands of the users.

2.4.1 Le Corbusier_Dom-ino House (1926-29)

After most of the Belgian population became homeless because of the social exclusion of the refugees, Le Corbusier had been expected to design an open system, a “platform”. That was just a skeleton which is a standardized, two-story house made up of concrete slabs supported on columns and a staircase. There was an unfinishedness which invites users to complete the house. This is a housing assembly line indeed, such as the one Henry Ford had invented only the year before. Ironically, Le Corbusier had the Fordist standardization in mind and yet produced the perfect architectural symbol for an era obsessed with customization and participation [10].

2.4.2 Walter Gropius_Törten Housings (1926-28)

Similar to Belgium case, it was the intention to create affordable living space for the growing population in Germany. Designing a prototype of modern living, a key element for Gropius was the rationalization of all construction processes under the primary consideration of reducing costs. Under these principles, prefabricated load bearing walls, inexpensive hollow slag-concrete blocks; and the ceilings with reinforced concrete joists were used [11]. In three phases of construction, different types of houses were built with the surface areas of 74 sqm., 70 sqm., and 57 sqm.

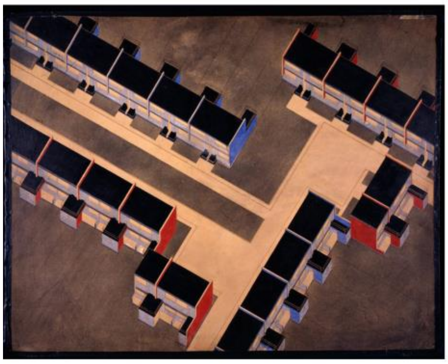


Figure 2.4 : Walter Gropius Törten Housings.

The individual assembly of the prefabricated building components was also intended to fulfil the specific wishes of the residents [12].

2.4.3 Frank Lloyd Wright_Usonian Houses (1946-54)

Frank Lloyd Wright designed The Usonian Houses, as a potential solution to the crisis in American urban areas. He was probably the most concerned with adjusting the design to the households in line with his "concept of houses being as different as their owners" (Sergeant, 1978). These openly designed housing schemes are divided into two wings: the more public living area and private bedrooms which meet at a service core. Designed to control costs, Wright's series of houses are single story which had no attics, no basements, and little ornamentation [13] [14].

2.4.4 Habraken's open building alternative (1970)

Habraken (1972) introduced different levels of decision making in the building industry which he called "support" and "infill". In order to accommodate unknown future changes, his aim was including the buyer that not occurred in mass-produced housings. On one hand, supports sphere contains more permanent features that cannot make changes such as load bearing walls. On the other hand, the infill sphere is likely to change according to different users, which was unique to each dwelling. The origins of the concept of "Open Building" (Open Bauwen) is best captured by one of John Habraken's finest quotes: 'We should not to forecast what will happen, but try to make provisions for the unforeseen' (Habraken, 1972). Although Habraken's method provides a significant increase in freedom of choice for the buyer, there are a few limitations. The potential for more involved 17 changes, such as adding an extra floor, is limited, since the construction method for the supports is based on mass production. Additionally, the need for buyers to confer with a specialist when choosing the infill means that this method becomes labor-intensive on larger projects.

2.4.5 IFD building (1990)

In the early 1990s, a design philosophy called "Industrieel, Flexibel en Demontabel bouwen" (Industrial, Flexible and Demountable building) was introduced (van den Boogaard, 1990; van Gassel, 2003). It has the goal of making buildings more sustainable, which it accomplishes in three different ways. The "Industrial" part of the name refers to the fact that buildings should be produced in such a way that they can be mass produced, resulting in more efficient production that saves resources and economies of scale that lower building costs. Flexibility is achieved in two ways. Allowing the initial client to modify the design removes the need for them to remodel.

Although IFD was not developed with mass customization in mind, it does share many of the same goals and the adoption of IFD facilitates mass customization. (Niemeijer, 2011)

2.4.6 Duarte's discursive grammar (2000)

Duarte's study is a process of providing mass-customized housing based on computer-aided design and production systems. It focuses on the design part, which mainly consists of an interactive system for the generation of design solutions based on a mathematical model called discursive grammar. A discursive grammar includes a shape grammar, provides the rules of formal composition, whereas the description grammar describes the design from other relevant viewpoints. The generation of a design proceeds first by producing a design brief from the user-prompted requirements and then by finding a solution that satisfies this brief. Search is largely deterministic, which decreases the amount of time required to find a solution, thereby making it reasonable to develop web-based implementations. The model is illustrated with a case study that includes a shape grammar developed for the houses designed by the architect Alvaro Siza at Malagueira. The end result of Duarte's work is a website where users can create their own home based on Siza's design pattern.

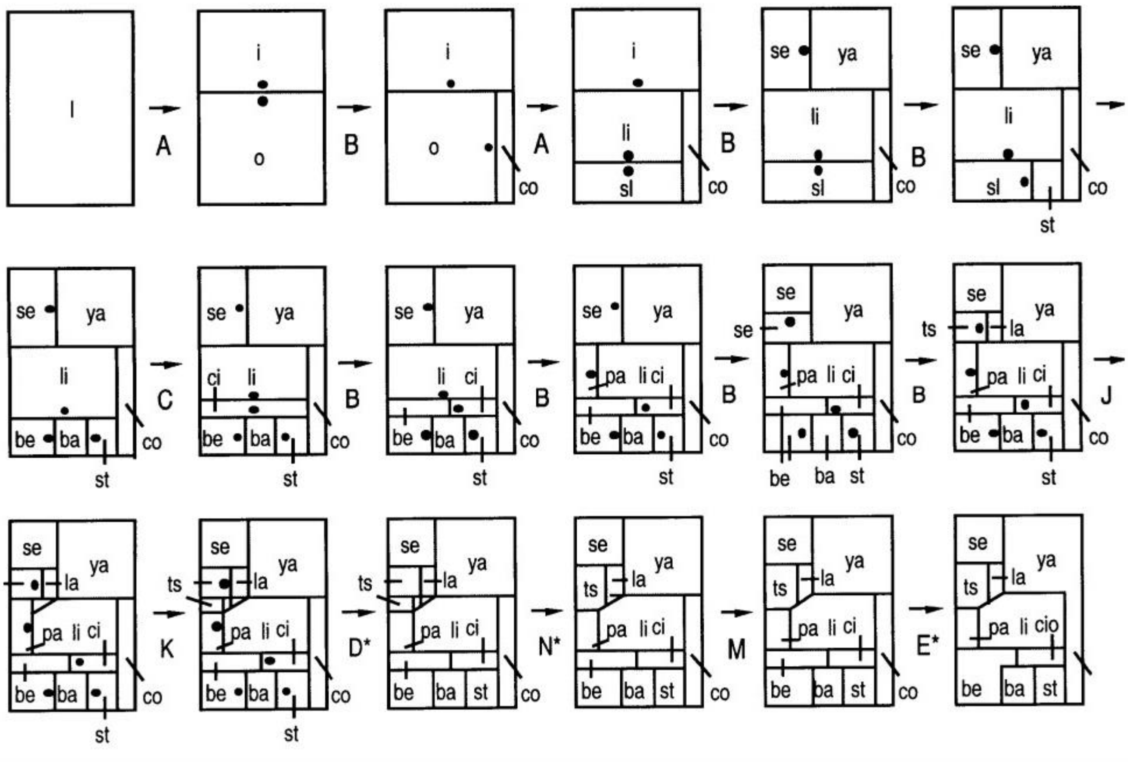


Figure 2.5 : A Discursive Grammar for Malagueira Houses (Duarte, 2000).

2.4.7 Smithwich's get physical assembly process (2008)

Smithwick has addressed various aspects of user-centered architecture in order to provide consumers with online tools that engage them in the design and manufacturing processes. His works outlined by the following scenario: A user joins an open-source online design community where he can upload and transform their digital design into a customized kit of interlocking parts that are locally manufactured and that can be assembled. These designs can be browsed by other members, discussed each other and anyone can participate joint designs, and so on. Instead of offering consumers just personalization, their web platform engages the consumer in the design, manufacturing and delivery process – giving them the tools to make decisions about how they impact the built and natural environment. The technology automatically and digitally translates the user's design into a unique kit of interlocking, easy-to-assemble parts. It can then be CNC fabricated and subsequently interlock together without the need for nails, screws or any additional hardware (Smithwick, 2008).

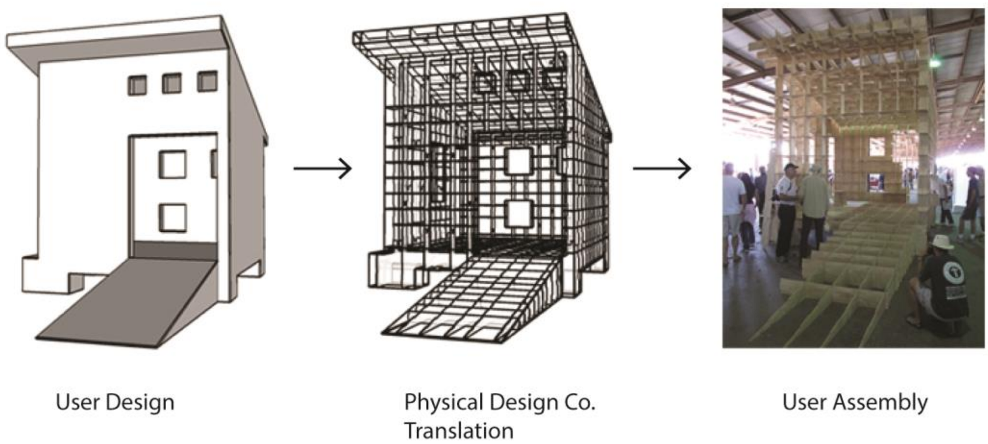


Figure 2.6 : Get Physical Process (Smithwick, 2008).

2.4.8 Plewe's user-centered approach (2008)

Plewe developed an alternative and an accompanying software to the existing tract housing paradigm in USA allowing a custom house to be designed in hours rather than months. This design tool included a 3D environment, a library of components and a platform combining these two inputs into a single one. Low to middle income families who wanted to create their own custom home would use this tool to search the library by using keywords such as "wood" or "cabinet", find the components they liked, add them to the 3D authoring environment, adjust the components until they're satisfied, and finally create construction documents for the contractor (Plewe, 2008).

This would enabled architects to design by arranging pre-designed multi-room components, as selected from a searchable database, into a single structure that uniquely fits a client's needs. For this purpose, sample houses are designed and economic estimates are made to determine the potential competitiveness of such a system with tract housing, as well as the system's potential effect on the overall economy of architecture. He also mentioned human-computer interaction and its cognitive aspects in his work.

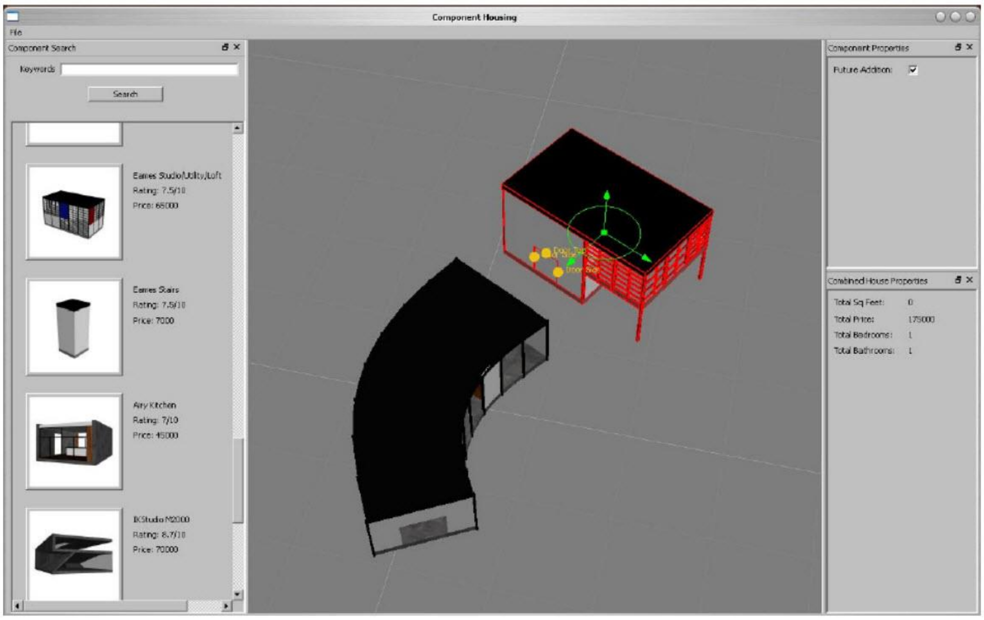


Figure 2.7 : Screenshot of H++ (Plewe, 2008)

Additionally, Phillips's work (2007) defines design as a process of searching, and provides the conceptual and technical framework to support search in web-based design tools for everyday users. The work is motivated by the notion of user-centered design, users are educated as co-designers to create their own living solutions, and the fabrication abilities to support it. He proposes a way of combining BIM, modern search methods and an OOP approach.

2.4.9 Overview of precedents

Each of the examples presented above set a certain base for the new model and provides the technical base for the work described in this thesis. For instance, Habraken shows how to create and use fixed and free spaces and bring a flexibility to the design of the houses, Smithwick's example indicates how to integrate the different users to the process by developing an online platform, Plewe cares about low to middle income groups needs and tries to define a user-centered design approach using a 3D environment simultaneously, and Phillips remarks the potentials of BIM and explores using it effectively in his research. In this research, it is required to investigate Turkey case, since different countries may have different user needs, and develop a new approach considering such notable studies.

2.5 The Important Roles Of Social Housings in Turkey

Turkey, like many developing countries, faced rapid urbanization following the WWII. (Uzer, n.d), There was a flow of the rural population towards big cities such as Istanbul, which was triggered by the mechanization of agriculture in the second half of the 20th century. During this period, existing housing and infrastructure stock got inadequate for the rural migrants. Therefore, cities started to expand in an uncontrollable way that illegal housing market appeared (Altaş & Özsoy, 1994). Then the government attempted on housing industry by asserting rapid housing production systems. This was partially driven by a large demand for the new houses that resulted as TOKI practices. TOKI, an institution founded in 1984 in Turkey, was originally designated to meet the rapidly growing demand for housing deficit in a planned manner.

Figure 2.8: An example of TOKI public housings (Evers, 2012).

It, however, has an opposing direction from the user-oriented design concept. More obvious characteristics of this kind of housing is rigid plan types, constructional standardization and homogenized typology while ignoring climate, land and culture. Therefore, this situation has caused the segregation of the local residents from the cultural and natural resources and public spaces of the city. Under these circumstances, a greater need for “customization” in architecture is needed to allow flexibility in the mass-produced social housings.

2.6 Discussion: The Use of Digital Technologies for User Participation in Housing Design

In Turkey, the housing development process is part of a dynamic network consisting of economic, political, social, natural and urban issues. After 80’s, in order to make sufficient number of dwellings, the government traded off customization which in time caused the low-income groups feel as outsiders. Still, these people cannot afford the services of an architect. However, the house, consists of high quality design items for everyday use, cannot be standardized because none of the inhabitants are exactly the same. Apart from social housings, people are buying a new house either by accepting the architect’s design, or they are offered a limited amount of alternatives to choose between. Even the limited number of the choices do not match the buyers’ needs as well as they might. Since, in most cases, they are not based on input of the buyers.

In this direction, Menges (2012) claims that, the advent of digital fabrication techniques has made possible the concept of “mass customization”, which is blurring the distinction and allowing industries to learn from each other. In Germany, Volkswagen offers a service where you can order your car and drive to the manufacturing plant to see it assembled. It is interesting to consider the adoption of a similar methodology in the building industry, as there appear to be no real reasons why the same could not be achieved with buildings. Projects where buildings can be customized are not uncommon. However, the construction of a 15-storey hotel in just 6 days in China in 2010 demonstrates that rapid construction is possible as well [15]. What remains is to combine the two while keeping the non-expert user in a defined stage. The result would be rapidly constructed, customizable housing, which is a significant improvement over current common practice.

3. DESIGNING WITH CONSTRAINTS

3.1 What is a Constraint?

Constraints could be thought as a limiting factor and a non-negotiable, “must have” requirement in an area of expertise. The simplest metaphor to exemplify a constraint could be functions carried out by a product when the action the user takes is correct. For example, a helmet is supposed to be worn on the head to protect it from impact of any collision. Its shape and physical structure limits the user to wear it on another parts of the body (Norman, 2002). This is an example of what we call a physical constraint. Correspondingly, in mathematics, constraints are conditions to an optimization problem must satisfy. In a Euclidean space the sum of the interior angles of any triangle is invariably equal to 180°. Generally, it is thought that anything that limits our ability must be negative, however, constraints are a part of the nature and our everyday life. Also, it is supposed among such authorities that constraints effect the creative thinking of an architect positively.

3.2 The Relationship Between Creativity and Constraints

“Man built most nobly when limitations were at their greatest.”

Frank Lloyd Wright

Creativity can be characterized as a complex activity, consisting of a special form of the problem solving (Newell et al., 1962). Cross (1997) takes this creative thinking as a process which has been characterized by the occurrence of an event called the ‘creative leap’. It is based on such a ‘co-evolution’ of the problem space and the solution space with the interchange of information between two spaces as a bridge. A creative event occurs as the moment of insight at which a problem–solution pair is framed: what Schon (1983) called “problem framing”. He used the notion of “surprise” in his theory of creative design, where it has the pivotal role of being the impetus that leads to framing and reframing. Also, he implemented that surprise is what keeps a designer from routine behavior. Akin and Akin (1996) thus analyzed the discovery of a creative solution that corresponds to the sudden attainment of an insight (A ha!) in the sketch of a design problem that was structured with several restricting frames of reference.

At any point in a design project, a number of constraints will exist: limitations or restrictions for what can or cannot be done in the design process, and for what the design should fulfill (Gross 1996, Hull et al. 2011, Joyce 2009). As it is impossible to initiate a creative process from nothing (Rosenman & Gero 1993), constraints are a precondition for creativity, and what is not constrained cannot be considered creative (Johnson-Laird, 1988). For instance, *creativity loves constraints* is one of Google's nine innovation principles [16], either Apple design chief focuses on utilizing material constraints as a core part of designing the iPhone 4 [17].

3.3 The General Usage of Constraints

Mostly, we need constraints to narrow down our possible options. Jerry Wind, a marketing professor at the University of Pennsylvania, observes "If customers have too much choice, they cannot make a decision, they freeze" [18]. Reducing the number of available options is more amenable, instead of giving various options to the user that often makes the job easier. The user will just need to deeply understand the rules and constraints of the application to use by certain amount of environments such as games, softwares, web applications, etc. In this chapter the usage of constraints will be discussed in several areas ranging from mathematics to engineering.

3.3.1 Mathematics

In mathematics, constraints has an important role by setting up a logical relation among several variables. A constraint restricts the possible values that variables can take while representing some partial information. Conceptually, it can be seen as a set that contains all the legal compound labels for the subject variables; though in practice, constraints can be represented in many other ways, for example, functions, inequalities, matrices, etc. (Tsang, 1993). The following is a simple optimization equation:

$$\min f(\mathbf{x}) = x_1^2 + x_2^4 \text{ subject to: } x_1 \geq 1 \text{ and } x_2 = 1$$

where x denotes the vector (x_1, x_2).

As given above, the equation minimizes the function of x that is the sum of x squared and x to the fourth power according to the constraints that x_1 is equal or larger than 1 and x_2 equals to 1. Both of them are hard constraints that should be satisfied in order to define the feasible set of candidate solutions. If there is not any constraint attached, the solution would be (0, 0) where f(x) gets the lowest possible value. However, the constraints cannot be satisfied since the value 0 is not equal or bigger than 1. So the solution set will be (1, 1).

Constraint satisfaction problem (CSP) is a mathematical problem defined as a set of variables that can take values from a finite and discrete domain and a set of constraints [19]. Constraint propagating and backtracking search are some techniques in CSP to make a given problem simpler to solve that iterates all the possible solutions. Solving problems on these constraints, is the process of communicating the domain reduction of a decision variable, which could not be a part of any solution, to all of the constraints that are stated over this variable [20].

3.3.2 Games & puzzles

Games and puzzles such as sudoku, n-queens problem, graph coloring problem, etc. include many constraints that should be satisfied in order to solve them. Sudoku, a combinatorial number placement puzzle, is a well-known puzzle among computer scientists. Although it has very specific features which can be exploited in solving it, it has been used for CSP solving. The problem is to place digits 1-9 on each row, each column, and 3x3 block, satisfying the constraint that using the digits just once. For example, in constraint propagation of Sudoku, the algorithm discards some of the values if it do not assigned to the solution. If we assign the digit d to cell c1, we eliminate d from all the domains of this cell's peers [21]. Below is an explanatory definition of constraint propagation.

> "Constraint propagation is a form of inference, not search, and as such is more "satisfying", both technically and aesthetically."
>
> E.C. Freuder, 2005.

3.3.3 Revit

Revit is a purpose-built application for building information modeling that helps architects and also respectively engineers to capture and analyze early concepts, and then better maintain designs through documentation and construction [22].

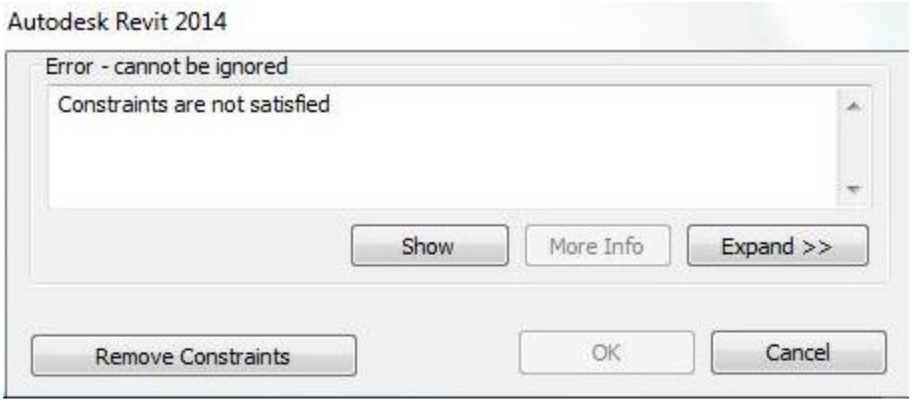


Figure 3.1: Revit Interface Showing a Constraint Warning.

In Revit, constraints build intelligence into the model, defining relationships and interdependencies between elements. Constraints can be created by applying locked dimensions and alignments, or attaching elements together such as walls and roofs [23]. Using this property, fixed and free walls can be created that users cannot make any change to the mechanical holes, stairs, elevators, *etc*.

Currently, it is limited to geometrical constraints only, such as specifying boundaries on lengths and distances between elements (Niemeijer, 2011). Other types those on materials or costs, are not yet supported. Additionally, constraints are mostly specified graphically or through entering values in predefined constraints, which somewhat limits the flexibility of the system. “Despite these limitations, it is a milestone on the way to bringing constraints into the mainstream in the building industry since it marks the first time that automated constraint checking has been available to a large group of architects” (Niemeijer, 2011).

3.4 Examples/Applications from Other Industries

Some industries have a long history of using constraints for verifying designs with applications ranging from automated circuit board design to ensuring software correctness and streamlining large-scale projects. Especially in mechanical engineering, applications include automatically inferring constraints from sketches (Anderl & Mendgen, 1996), creating designs for piping (Gross, 1996) and parametric solid modelling (Bettig & Shah, 2003). This chapter examines the way constraints are used in other fields and contrasting this with the adoption of constraints in the building industry.

3.4.1 Industrial engineering

In manufacturing, a constraint is often referred to as a bottleneck which prevents the system from achieving its goal. Goldratt (2004) revealed the theory of constraints in his book “The Goal” which is a scientific approach and a management philoshopy for identifying this limiting factor. The book hypothesizes that every complex system, including manufacturing processes, consists of multiple linked activities, one of which acts as a constraint upon the entire system such as “the weakest link in the chain”. This means that processes, organizations, etc., are vulnerable because the weakest person or part can always damage or break them or at least adversely affect the outcome. It becomes crucial to determine how to strengthen the chain (Tabish & Syed, 2013). Thus TOC provides a specific methodology for identifying and eliminating constraints, and restructure the rest of the organization around it (Cox & Goldratt, 1986).

The five steps are:

1. Identify the system constraint

2. Decide how to exploit the constraint

3. Subordinate and synchronize to the constraint

4. Elevate performance of the constraint

5. Repeat the process

The five focusing steps aim to ensure ongoing improvement efforts are centered on the organization's constraints. In the TOC literature, this is referred to as the process of ongoing improvement (POOGI) [24].

3.4.2 Software engineering

Constraint networks and constraint satisfaction problems have a long history in artificial intelligence starting from the seventies. In the software engineering industry, constraint programming is the study of computational systems based on constraints. The idea is to solve problems by stating constraints (conditions, properties) which must be satisfied by the solution [25].

There are several ways of applying constraints to a unit of code, such as constraint propagation (to eliminate the options), computer graphics (to express geometric coherence), natural language processing (to parse languages correctly), database management systems (to store, modify, and extract information from a database), operations research (like optimization problems), numerical analysis (to make an approximation), etc.

3.4.3 Mechanical engineering

In a lot of respects, mechanical engineering and building industry hold some common properties in using constraints. Both disciplines have to obey a series of constraints while designing three-dimensional objects. A mechanical designer controls the parts separately. So the use of constraints in mechanics aims to put these individual constraints together to tell us about a system's behavior. For example, in a fluid circuit, it can be specified which constraint say how a hydraulic piston and a control valve operate. These relate the internal pressures and flows to the configuration and motion. We can then put these constraints together in order to understand how the pressure and flows between components relate [26].

In addition, there is a concept in mechanics, exact constraint design, manages the degrees of freedom to neither underconstrain nor overconstrain a device. Because overconstrained or underconstrained devices simply have no function. If they are exactly constrained, parts will fit together precisely and without backlash for example, kinematic couplings (Layton, 1999).

3.5 Limited Adoption of Constraints in the Building Industry

The building industry has so far not seen a significant adoption of constraints for varying reasons. One of those is the slow adoption of CAD in the architectural design. For example, the only major CAD program to offer support for constraints is Revit (Strömberg, 2006), and even then the support is limited to basic geometrical and structural constraints. Another reason is the nature of the architectural design takes the process holistically rather than distinct components designed partially. For this reason, architecture design constraints must be created and accepted with care.

Reitman uses the term "constraints" quite broadly to refer to any or all of the elements that enter into a definition of a problem. Simon observes;

> "One of the interesting features of many of the problem instances…is that even though they generally would be considered complex, they include very few constraints as given. Composing a fugue is a good example. Here the main initial constraint, and it is an open

> constraint at that [i.e., one that is incompletely specified], is that the end product be a fugue. All other constraints are in a sense supplementary, generated from one transformation of the problem to the next." (1973)

In the architectural realm, the architect begins with the sole problem of designing a house. As stated in Simon's "The Structure of Ill Structured Problems" (1973), "we can imagine a design process that proceeds according to the following general scheme. Taking the initial goals and constraints, the architect begins to derive some global specifications from them." Therefore, the metagoal of design can be described as a process of transforming such constraints into design descriptions (Gero, 1990), using constraints in both a generative manner as well as in an evaluative manner (Ball et al., 2010).

Constraints can also be compared to universal quantifications from the field of mathematics. Quantifications indicate how many elements of a given set satisfy the given predicate. For instance,

$$\forall x \in N. x \geq 0$$

means "For all elements x in the set of natural numbers, x is more than or equal to zero". The similarity with constraints, such as "dormers must be higher than 1.5 m", can easily be seen (Vries et al., 2000).

Therefore, a typical design involves thousands of rules, or constraints, at many different levels. So, it is not feasible for large-scale projects to give total freedom to the user that architects have reason to limit user choice. The computer becomes a laboratory instrument which supports the investigation of the theory.

3.6 Constraints in Architecture

According to Gross (1985), "Constraints are rules, requirements, relations, convention, and principles that define the concept of designing. There are many constraints on a design imposed by nature, culture, convention, and the marketplace. Some are imposed externally, while others are imposed by the designer".

Architecture consists of a collection of constraints according to their influence on design. In this research, a new way of subdividing these constraints is found based on how they are affected by the constraints: direct and indirect categorization. Direct categorization includes *structural constraints, geometrical constraints, material constraints,* etc. Indirect categorization includes *time constraints, financial constraints, aesthetics constraints,* etc.

Direct influence

Structural constraints

This kind of constraints regard the strength of architectural elements, such as the minimal supportable load of a floor.

E.g. A floor should carry 200kg/sqm. for rooms, and 350kg/sqm. for balconies.

E.g. Width of any internal door should be maximum 1.5 m. Figure 3.3. shows an example of a geometrical constraint made in Revit.

Geometrical constraints

These are constraints on dimensions, such as the length or area of an element.

E.g. Minimum distance between two walls for kitchen must be at least 2 m.

E.g. Bathroom and kitchen preferably shall be adjacent.

Material constraints

Constraints in regard to the properties of materials, such as the durability of wood.

E.g. The material of floor of bathrooms must be ceramic, granite, laminate or vinyl.

E.g. The depth of profiles of plastic frames must be at least 0.03m.

Building physics constraints

Constraints about the climate of a building, such as the maximum allowable temperature in a room.

E.g. Any exterior wall should be insulated, or if the apartment block is located in Erzurum, glazing should be at least 3 layered.

Indirect influence

Financial constraints

Constraints on the cost of parts, the choice of materials of a design, or the design as a whole.

E.g. The material of the window frames must be plastic based.

Visual constraints

Constraints intended to achieve a certain look, such as a required façade material of a specific color.

E:g. Color of the internal walls cannot be different.

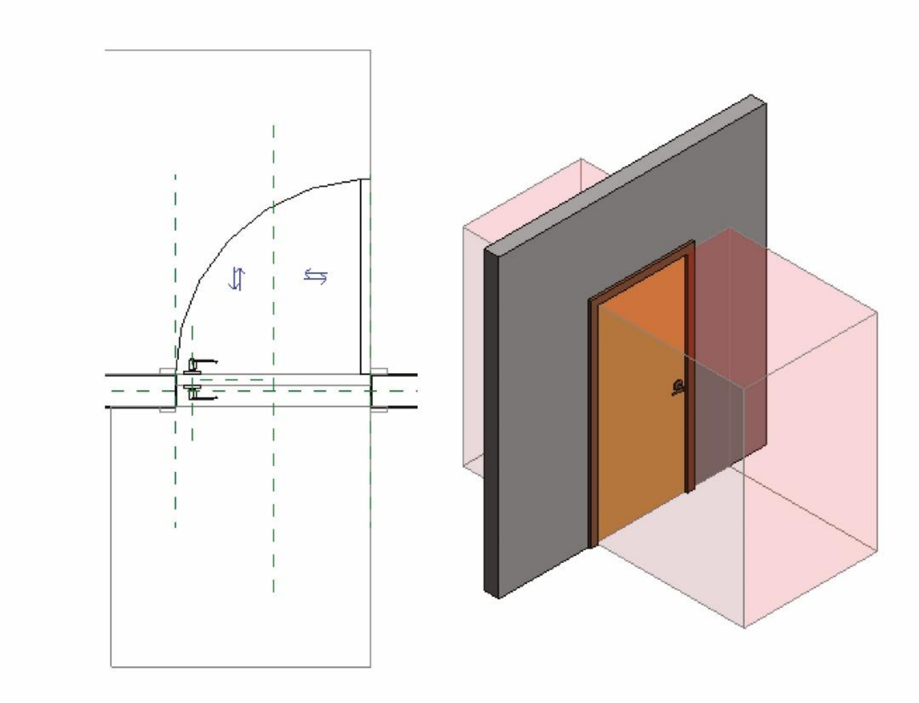


Figure 3.2 : An Example of a Geometrical Constraint in Revit. [6]

Besides, some constraints cannot be categorized as in the above examples. However, time constraints, resource constraints, etc. are important for understanding the general perspective of the specific concept.

Making classifications will be beneficial primarily to the clarity of a deep understanding of constraints in architecture. In this research constraints are used as a starting data in order to involve the user as an input.

3.7 Discussion: How Constraints Effect Creativity

Constraints can also act as a catalyst for innovation and creativity in some cases. Limited amount of empirical research have been conducted for examining the impact of constraint on creativity, however most of them have focused on time constraints. According to Amabile (1996), the presence of time deadlines or production goals has typically been described as a negative influence on creativity because it discourages exploration and increases reliance on status quo ways of thinking and doing. However, time constraints can have a positive impact on creativity; at least if there is enough time and average external conditions. For example, Baer & Oldham (2006) found "a curvilinear relationship between time pressure and individual creativity", where moderate levels of time pressure had positive effects on creativity. "As designers get closer to running out of time, they can have the most creative ideas that they had not thought about before".

According to Rosso (2011), a lack of material resources is another potential constraint that has received some research attention and mixed empirical findings. On one hand, "the availability or abundance of material resources might negatively impact creativity" (Csikszentmihalyi, 1997). On the other hand, Amabile et al. (1996) has suggested that, "creators need to feel comfortable and provided with sufficient material resources in order to be maximally creative".

In sum, architects, as most deisgn professionals, are interested in using constraints throughout the design process. Since, this is a different philosophy from that of conventional expert systems and other rule-based approaches. For this aim, it is developed a prototypical model for the design case which offers an effective access to connect computational building modelling and in turn facilitates the new approach to mass customized buildings.

4. CONSTRAINT BASED MODELLING IN ARCHITECTURE

As with the products of several industries, the products of the building industry have to comply with a multitude of constraints, such as building codes, technical requirements, architect's intentions, and client's brief. Verifying all these can be done manually, but due to large amount of both designs and rules, this is exceedingly labor-intensive. So, it is preferable to view design at a higher level having the power of massively influencing the architecture than the traditional collection of two-dimensional lines. "An example of constraint handling can be found in Building Information Models, and more specifically Revit, which offers automatic checking for the unwanted intersection of elements in the 3D model" (Niemeijer, 2011). The ability to refer to building elements, such as walls and windows as a whole, makes modifications easier to perform and greatly simplifies automated model verification. For this reason, a discussion of standard for BIMs in the architecture domain is included in this chapter. In this scenario, the constraints serve more as a reminder than as the defining factor in the design. Thus, the infinite number of solutions requested by the user will be restricted according to the pre-determined constraints that all design modifications can be done concurrently rather than sequentially.

4.1 Methods of Using Constraints

"There are two ways of dealing with constraints, depending on who creates the design — the user or the computer" (Niemeijer, 2011). First is to take the constraints as an input and try to find an appropriate design. Second one is to make the design and then check. Although the aim in both approaches is satisfying all of the constraints, they have different characteristics and different application domains.

4.1.1 Constraint solving

The first method is constraint solving which is a bottom up approach, *i.e.* taking the constraints as an input and trying to find a design that satisfies those (Kelleners, 1999;

Eggink et al., 2001; Belbidia & Alby, 2003; Donath & Böhme, 2007). It is used to generate the design using variables with infinite domains.

An example can be a 1000mmx1500mm window placement in a 3000mmx5000mm wall with a constraint being that the window is not closer than 500mm of any edge. There will be an infinite number of solutions since the position is a continuous variable. This results in a solution space of many possible options. However in construction, the buildings are built in some degree of accuracy as an artifact. If we assign a 5 mm of accuracy, the position variable can be turned into a discrete variable makes the domain decreased. Of these 6 million possible solutions, 500x3000 = 1.5 million are valid.

$$500 < x < 2500$$

$$500 < y < 1500$$

$$k = \frac{x}{5} \quad (k \in N)$$

This solution space can also be significantly reduced by applying constraint propagation (Kumar, 1992; Sannella, 1994; Jussien & Lhomme, 2002), which depends on the changes. The only requirement for propagation is the existence of dependent variables. For instance, if the level of floors are determined, the vertical position of the walls will be fixed to a single possible option reducing the overall solution space. The building industry contains enough number of dependent variables, however there are also a sufficient number of independent variables which must be taken into account. It means that there is a limit on how far the solution space can be reduced. A typical way of working will be to create a design first and specify and add the constraints afterwards (Niemeijer, 2011).

4.1.2 Constraint satisfaction

A commonly referenced definition for the constraint satisfaction problem views it as “composed of a finite set of variables, each of which is associated with a finite domain, and a set of constraints that restricts the values the variables can simultaneously take” (Tsang, 1993). In artificial intelligence and operations research, constraint satisfaction is the process of finding a solution to a set of constraints by imposing conditions that the variables must satisfy. A solution is therefore a set of values for the variables in the feasible region.

One way in which to represent binary constraints is to use matrices of boolean values. For example, assume that variable *x* can take values 1, 2 and 3, and variable *y* can take values 4, 5, 6 and 7. The constraint on *x* and *y* which states that "*x + y must be odd*" can be represented by a matrix, as shown in Figure 4.2 (Tsang, 1993).

$$
\begin{array}{cc|cccc}
\multicolumn{2}{c|}{C_{xy}} & \multicolumn{4}{c}{y} \\
 & & 4 & 5 & 6 & 7 \\
\hline
 & 1 & 1 & 0 & 1 & 0 \\
x & 2 & 0 & 1 & 0 & 1 \\
 & 3 & 1 & 0 & 1 & 0
\end{array}
$$

Figure 4.1 : Matrix representing the constraint between x and y (Tsang, 1993).

The reason why constraint checking methodology is used rather than constraint solving in this research has several reasons. For simple constraints such as "the height of the wall must be between 2 and 2.6 m", it is easy to generate all possible valid solutions (Niemeijer, 2011). Computing all combinations of all the possibilities for each element results in a list of all valid design alternatives, from which an alternative can then be picked using any criterion, such as minimal cost. Depending on the size of the solution space, this can take a very long time (Ian et al., 2006).

Because, the goal of this research is to have a computer support for both the architect and the buyer, constraint checking is used in this proposed model to make an initial design and check. This method gives users the freedom to make the design themselves and only indicates problems to them, matching the design intent. Thus, the infinite number of solutions requested by the user will be restricted according to the pre-determined constraints and all design modifications can be done concurrently rather than sequentially. It also shifts the task of navigating the solution space to the user, which makes it easier to avoid suboptimal solutions. Thus, the architect is to create a master design and additionally specify a series of constraints setting boundaries to what the users are allowed to change.

4.2 Proposed Model

When people are buying a new house, they typically accept the architect's design, or they are offered a limited amount of alternatives to choose between, such as two different kitchen types or the optional addition of a window. This customization is only very limited though, as all design alternatives offered by the architect have to be fully designed up front. This means that people are not able to get the exact house they want. And also it is not uncommon, especially for low/middle income people, to immediately start remodeling after the house has been built in order to get the house they actually wanted.

This of course is a very inefficient state of affairs, leading to an unnecessary increase in both cost and waste. "It would be preferable for buyers to be able to make more extensive changes to the design of the house in the design phase, so that they can get the house they want, eliminating the need for an additional remodeling step" (Niemeijer, 2011). This same basic philosophy is advocated by Hennes de Ridder in his "Living Building" concept (de Ridder & Vrijhoef, 2005). In this way, the architect confronts a problem having to make a lot of different designs since it is costly and time consuming. And also, iti is impossible to sit down with every family and make a customized house for each of them. In order for this philosophy to be feasible in large-scale projects, a different method must be used. An explanatory process diagram for an alternative can be seen below on figure 4.2.

Instead, a design process may better proceed according to the following scheme. First, external inputs (*e.g.* social structure, user profile, level of income, physical environment, etc.), within a diameter of assumedly 500 m., are gathered in order to create a base for the design itself. This phase can be understood as a pre-customization at the urban scale where the potential user parameters are specified. For instance, the footprint of the building, the number of floors, the square or cubic measurement, the need for additional functions, balcony, socializing areas or security requirements, etc., can be determined considering the functions among the built environment. Thus, the non-changeable part of the building, skeleton and its core with the surroundings, will be developed at the end of the first part of the process.

In the second phase, the design gets more and more specific regarding the user inputs determined before. This phase is composed of two main parts:

Firstly, the user makes some decisions using a multiple-choice interface similar to how Volkswagen does with the help of a drop-down menu. The choices, depend on the user's family structure, socio-economic level, etc., shape the building by specifying the informations such as orientation, floor level, number of rooms, material segment, etc., which will guide for the next step.

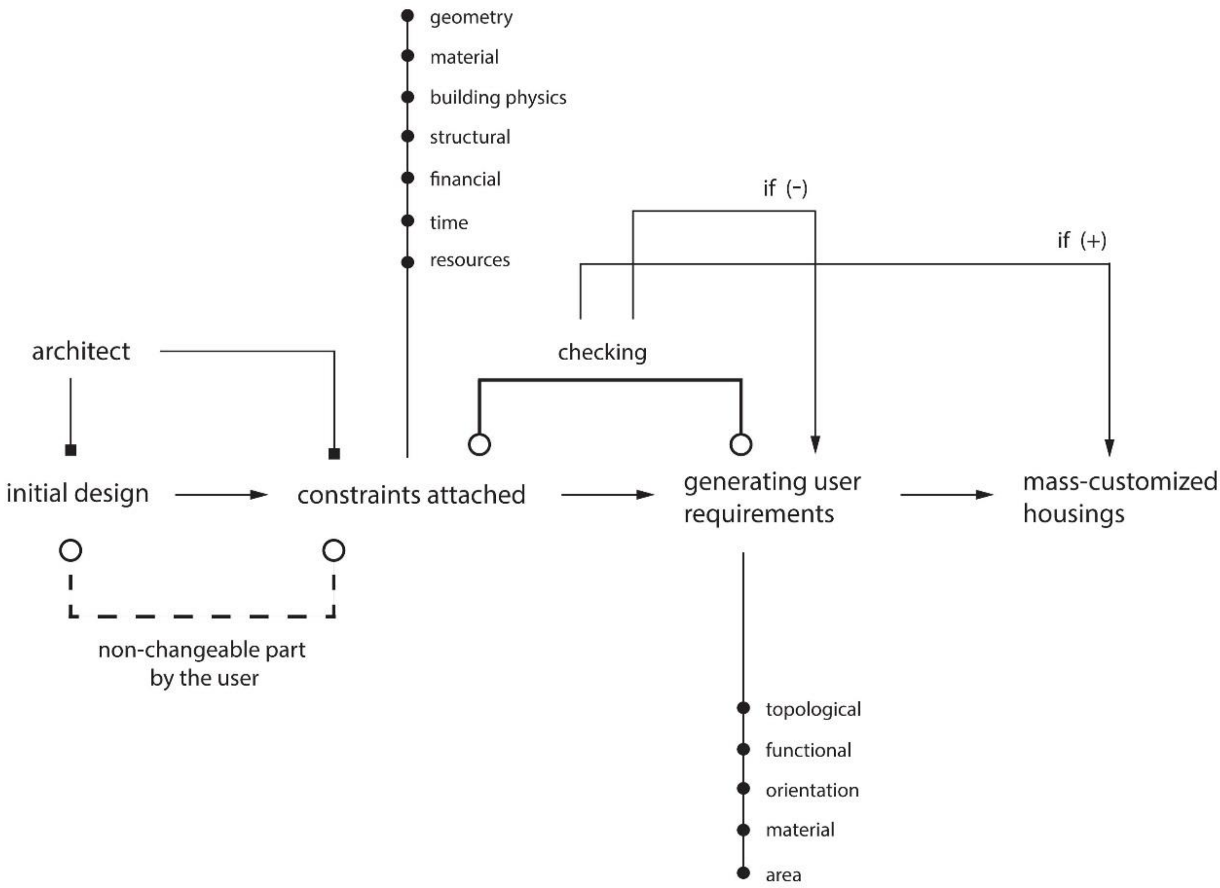


Figure 4.2 : The Proposed Process Diagram (Developed by the Author).

Secondly, the best possible option of a design is chosen which has generated under the control of the architect and the client priorly. This base model, generated according to the pre-defined inputs and preferences of the user, can simultaneously be manipulated in both 3D view and the plan view. Since the list of his choices and correspondingly the cost estimate will be determined, he will make some amendments in a controlled manner by pursuing them. Accordingly, the user can make various arrangements within the pre-defined constraints by the architect (and client), such as topological (relocating the rooms), functional (adding a utility room), material (changing the material of the floor) or areal (sliding a wall through the window). For example, if the user selects the mid-level material segment in the previous section, the system will not allow him to pick granite for the wet areas because of the cost issues. The same rule will be valid for the additional walls in which the system inhibits adding an element with a degree of 45. After these manipulations, the rise in the expected cost will make user to look back and change/optimize his choices. However, provided customization has a dead-line in order to stick to the process and ensure the predicted cost. If the user enters into the process as early as he can, he will get relatively more customization among other users.

Consequently, this research explores a system that supports user-participation in the process of creating housing designs. The user will get involved to the process as a sub-consultant and they can play an active and participatory role in the built world around them while giving the architect appropriate control over his design. He will just need to deeply understand the rules and the constraints of the application used by certain amount of environments.

4.3 Prototype Implementation

In order to explore the possibility of such a system, a prototype is developed (see figure 4.3 for an overview). After leaving fixed spaces, like entry and vertical circulation of the building, if the user wants to have a bathroom adjacent to the bedroom, he can relocate the rooms (dashed walls) by pursuing the constraints.

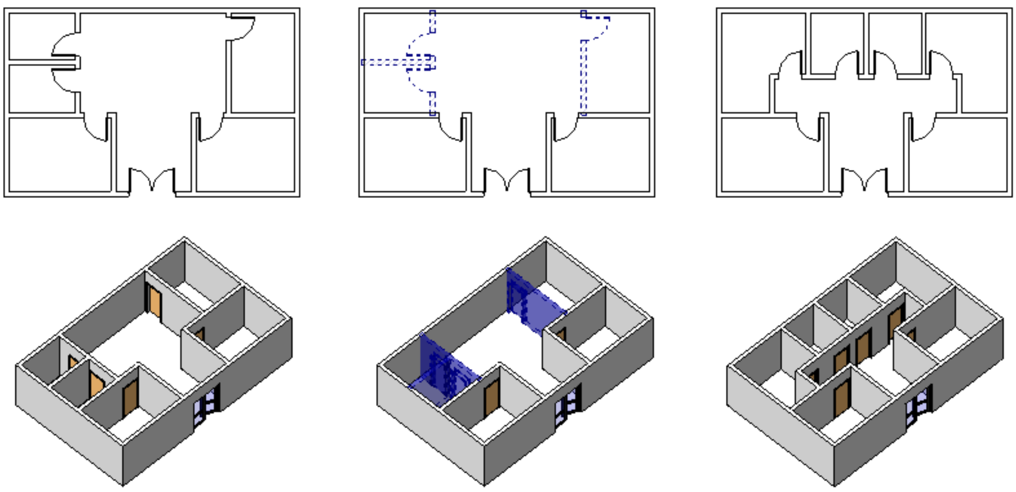


Figure 4.3 : An Example Prototype Showing in Color What Users Allowed to Change.

After specifying the master designs according to external data and user preferences, design manipulations are started to customize the designs. As boundary conditions, the position of the exterior walls and the sanitary cores are fixed (see figure 4.7), which means that all six degrees of freedom (three degrees of position and three degrees of rotation) are constrained. The other walls have no constraints placed upon them, and can be freely moved and rotated. Figure 4.4 shows the fixed and free walls that were implemented for this prototype.

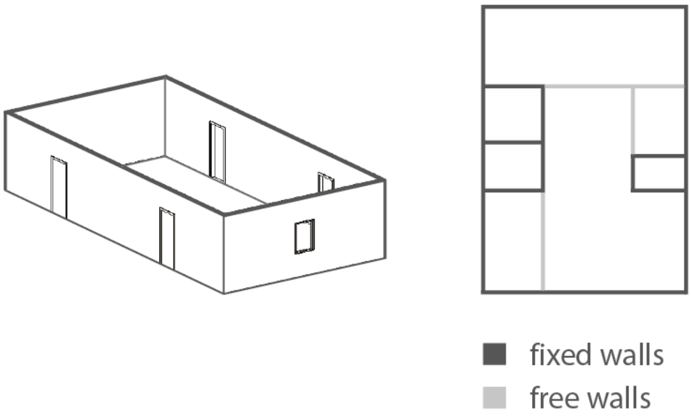


Figure 4.4 : Fixed and Free Walls as Constraints Used in the Test Case.

It can be considered that there are two different usages: a young professional and a two-children family. First case, a single young professional can prefer a flat on the south facade and the 15th-20th floor range of the apartment. He can also chose an 80 sqm. one among 60, 80, 95, and 105 sqms. with the high-level material segment, because he does not need any additional rooms. Second case, a two-children family, can prefer a flat on the west facade with the mid-level material segment because of the cost getting high than the expected. They can also choose a 120 sqm.one among 90-120-140 sqms. and the 5th-10th floor range of the apartment.

Hence, a single young professional can reduce the square footage of a bedroom and add a dressing room, so the living area can turn into both sleeping and working spaces. On the other hand, a two-children family can divide the space for two rooms into three equal rooms in order to provide extra rooms for each children. Subsequently, the users get the opportunity for making preferences according to their life-style and family structure while monitoring their choices and controlling the cost simultaneously. At the end of the process, customized house will arise in control of the architect and the client with the mass production efficiency. See figure 4.8 for two different alternatives of a young professional below.

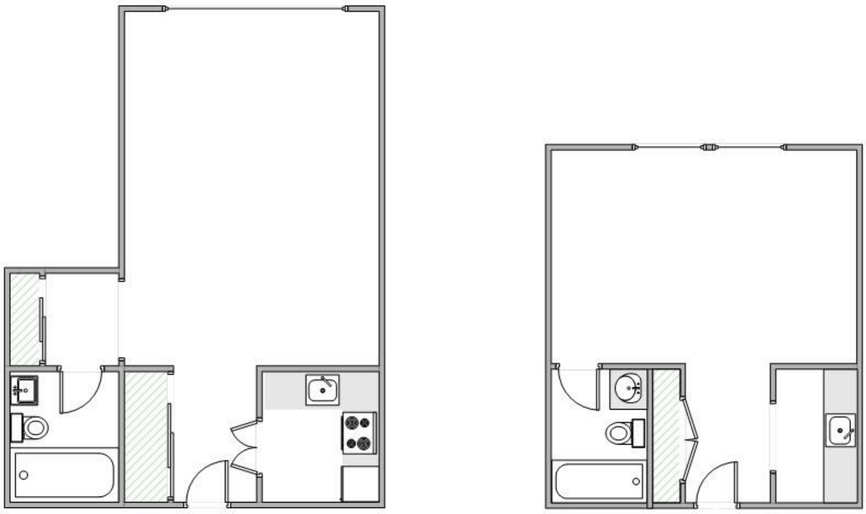


Figure 4.5 : Two Alternative Designs for a Single Young Professional.

4.4 Building Information Modelling_BIM

It is to be expected that the designs made by the buyers will not be in full accordance with either the building codes or the architect's intentions. Therefore, it is preferable to be able to automate this checking process and ideally to perform it in real time while the buyer is modifying the design. In order to give buyers this level of freedom, it is important to ensure that designs produced by the buyers comply with the architect's vision, as well as the other requirements that are imposed on houses, such as building codes. This way he can be guaranteed that the resulting designs have no trivial problems, freeing him up to look at more complicated criteria that are difficult or impossible to automate, such as aesthetics.

"Traditionally, building designs are stored in CAD drawings, which are little more than a collection of lines. Humans can interpret these drawings, but computers cannot" (Niemeijer, 2011). Since the design is normally represented by several drawings (plans, sections, etc.), changes to one drawing have to be manually changed in all the other drawings as well, which increases the risk of errors, leading to higher costs. One way of making the required information easily available to the computer is to represent the design as a collection of building elements, with information stored in the properties of the elements rather than a series of lines. This methodology is called parametric design (Roller, 1991; Matcha, 2007). This means that, for example, a window is not merely a group of rectangles, but a single element with properties such as width and height, making it significantly easier for the computer to reason about the design.

In a BIM, parts of the building are not stored as lines but as actual objects. For instance, a window, except for being a rectangle, it is an object with a width, height, price, manufacturer, material, *etc*. This means, among others, that information from the design is available to all the applications used in the design process, *e.g.* the contractor's financial application can automatically sum up the cost of all the building parts (Niemeijer, 2011). It also implies that any change in the design only has to be made once. After that all the drawings can be automatically re-generated. One of the advantages of BIM mentioned earlier was the improved communication between tools. Aside from the properties of individual elements, BIM may also store information that is not restricted to a single element, such as relationships between elements, and non-geometrical information, such as climate information. The parametric models within the scope of this thesis are all considered to be BIM.

4.5 Integrating Constraints to Revit

The first common application in architecture to offer support for constraints is Autodesk's Revit (Strömberg, 2006). Revit is a "parametrically based CAD system" with an integrated model and a highly interactive environment for specifying constraints by the architect. For example, if the position of a wall is specified by a locked dimension, it become a constraint that nobody can change its position or it will move while keeping the dimension length the same as it was. Also, an equality constraint can be created in order to keep a chain of dimensions at equal values. When the total length changes, each individual dimension value will change according to new length.

Because constraints are very powerful in the system, Revit can provide these kinds of automatic checking for the unwanted manipulations and intersections of elements in the 3D model. When applied well, the architect can get a very flexible building model, where changes propagate automatically to all elements that are constrained [27].

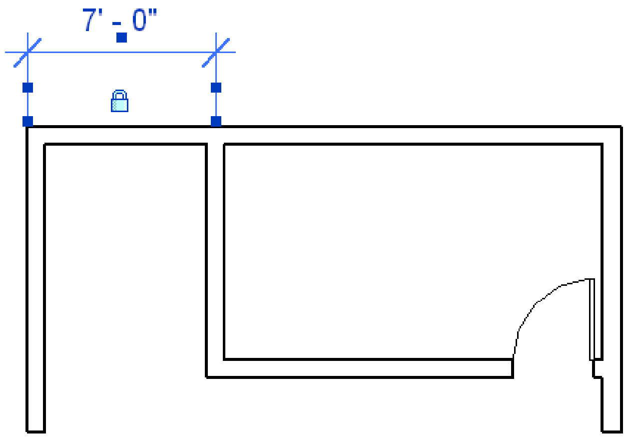


Figure 4.6 : Dimension Constraints in Revit.

Alongside geometrical constraints, the program also supports cost and material constraints indirectly by calculating values. A schedule is a tabular display of information, extracted from the properties of the elements in a project. As the architect make changes to the project that affect the schedule, it automatically updates to reflect those changes. He can, for example, calculate the area of a room or count the number of specific objects, like interior doors. The software will archieves this values using the schedules. A client can also implement such constraints to the system in order to control the cost, such as using material cost estimation datas.

Roof Material Takeoff				
Family and Type	Material: Description	Material: Are	Material: Cost	Estimated Cost
Basic Roof: Wood Joist - Insulation on Plywood Deck - EPDM	EPDM	595 m^2	16.00	9522921.98
Basic Roof: Wood Joist - Insulation on Plywood Deck - EPDM	Plywood	595 m^2	13.40	7975447.16
Basic Roof: Wood Joist - Insulation on Plywood Deck - EPDM	Rigid Insultion	595 m^2	50.80	30235277.30
Basic Roof: Wood Joist - Insulation on Plywood Deck - EPDM	Wood Joist	595 m^2	5.35	3184227.04
Grand total: 8		2381 m^2		50917873.49

Figure 4.7 : Arbitrary Sample Screen Printout in Revit.

I take the advantages of constraints in the architectural industry such as, structural, geometrical, material, building physics, financial, visual. All of the constraints show me how to integrate them to the design process. To make the usage of constraints viable in the proposed system, a property which allows importing data from external resources is investigated. Revit gets the parameter from the internet, and then uses this parameter to generate a family (See Figure 4.4 below) that relies on as follows:

Revit <——> Database <——> Outside Program

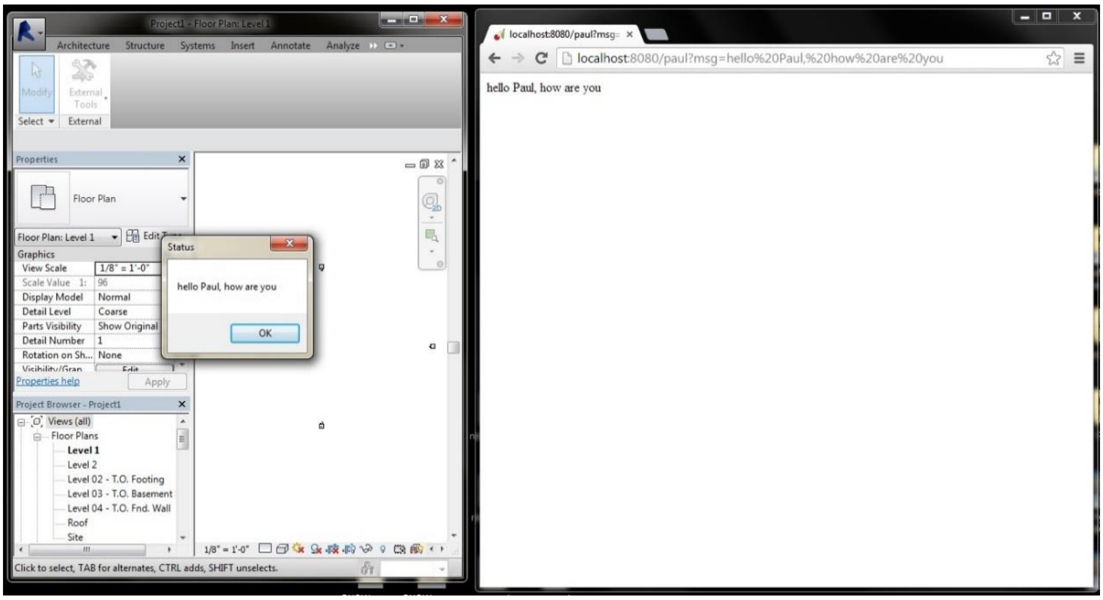


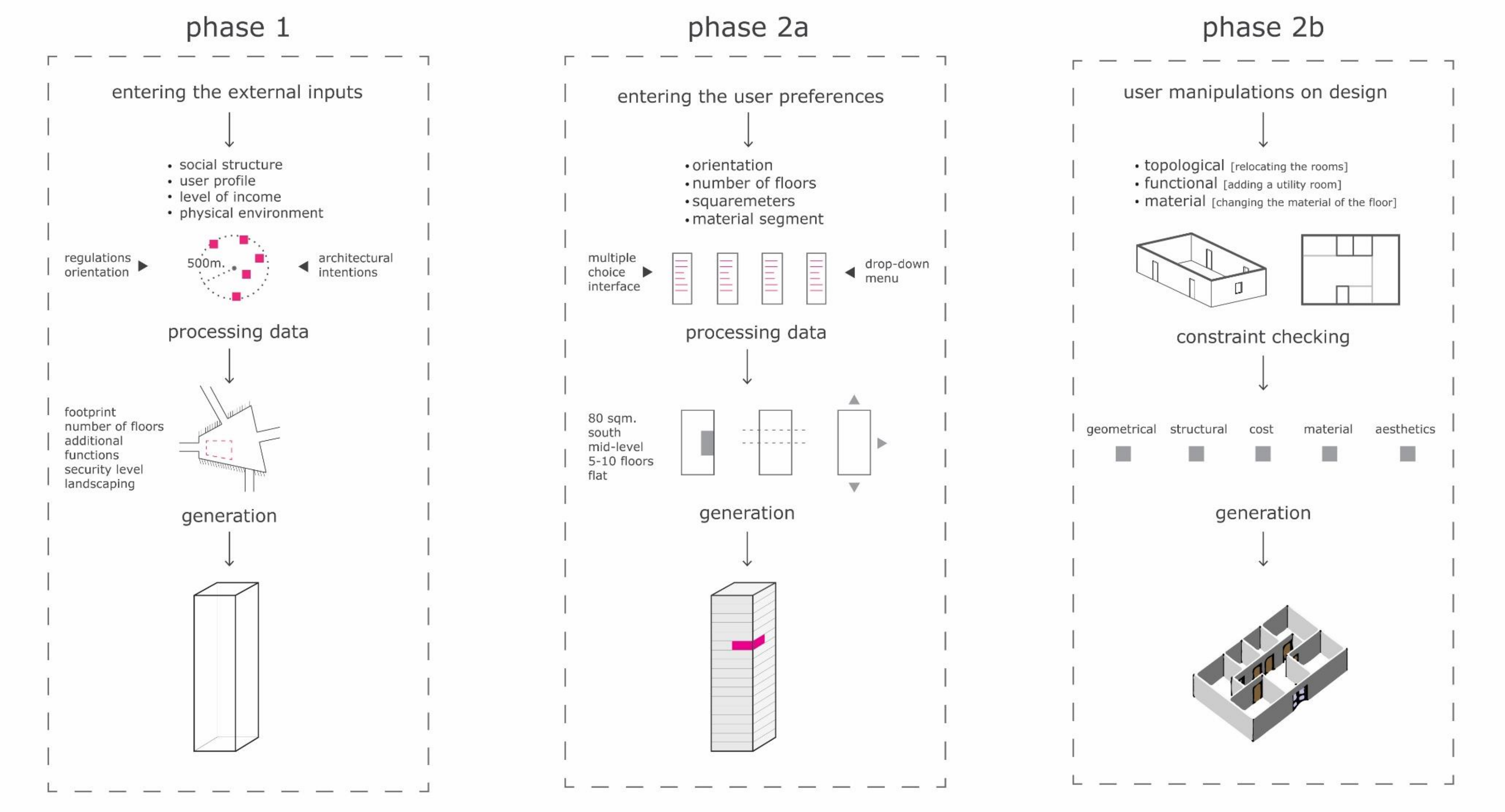
Figure 4.8 : A Screenshot Showing How Revit Imports Data from Outside Sources.

4.6 Discussion: Making Customization Available for Users in Housing Design

Custom-designed housing has provable benefits, but has remained unreachable for the vast majority of home buyers. In attempting to make customized housing compete with the conventional mass-produced housing industry, this thesis have been searching for efficiency through using parametric modelling systems.

Having a parametric structure, BIM facilitates complex interrelations between physical building elements and abstract objects like space. It also creates links between geometry/data and behavior, *e.g.* a window has a specific behavior and must be related to a wall or roof and has a specific position. Intricate relations can be created between dimensions or positions of several elements, so that for example when a floor-height changes, all walls will automatically change.

The focus on constraint entry in this thesis presumes that constraint checking in the building industry is feasible. This was expected to be the case, since similar techniques have been used in other industries for many years. The literature review in previous chapters of this thesis shows that the same holds true in the building industry, freeing the way to look at the constraint checking process in more depth by using constraint-based systems characteristic to BIM. However, there are yet no client-oriented applications that have all of the proposed functionality, specifically the constraint checking. Nevertheless, there are pre-existing solutions for solving constraints in the subsystems of a wide variety of 3D modelling programs. In fact, for each subsystem, free and/or open source systems exist and this significantly reduces the cost required to develop such a system which makes it more feasible to use in real housing projects. In this way, the proposed model is reasonably successful in allowing people to define constraints while creating a mass customization. Also, the architect has a key role in the proposed process by making the master design and entering such constraints. This is one of the more important aspects of the research. It is a challenge for architects and contractors to adopt using such softwares in practice.



Detailed Process Diagram.

5. CONCLUSION

5.1 Thesis Summary

Mass customization is a concept of great interest for researchers as a strategic mechanism applicable to most businesses. It addresses individual customer needs such as in buying a new pair of shoes, a personal computer, an automobile, or even a can of coke. These industries have changed and developed their production line in order to accommodate this user-oriented approach. It is a process for aligning an organization with its customers' needs (Salvador, de Holan and Piller, 2009). Also, developing a set of organizational capabilities that will, over time, supplement and enrich an existing business. Since, it is possible to create the opportunity for mass-customization in a world increasingly dominated by technologies of information and communication. Accordingly, this concept has spread among several industries through fully digital design and production processes.

However, as highlighted in the introduction, although MC has been part of research for more than a decade, the literature has not yet come up with a commonly accepted understanding and adoption of this term in the building industry and more specifically, the architecture domain. In the 80's, urbanization affected Istanbul in a negative way. The character of the cities and neighborhoods was shaped using mass-production tract housing methods where similar home plans are copied, mirrored and rotated. The result of this strategy led to standardized communities with habitation that is insensitive to personal desires. These cheap and hastily built houses were usually implemented for expedience and especially in the social housings, the design process was essentially limited in favor of cost and time effectiveness. The occupants were not included in the design process and no agency was available in the design of their home. Although very few agencies were available in the housing selection part that they could offer only a limited variety. In these circumstances, mass customization, especially for a life-time product, should not be ignored.

This thesis attempts to close this gap by proposing a model/system based on three findings in the scope of this thesis. First, mass customization should only be used to describe company–customer interaction at the operations level of the value chain. Second, mass-customized products should have production cost similar or only slightly higher than mass-produced goods. Finally, in mass customization, digital design and manufacturing tools should be used in order to reach MP efficiency and support both architect and the buyer. Based on these results, the proposed model is intended to develop a method for architects and include the user to the process. However, giving buyers more freedom of choice when it comes to the design of their new home will require their participation in the design process. Since the user has practically no architectural experience, in most cases, the architect as well as the client will have reason to establish some constraints to the system of customization.

Design, as a discipline and practice, is a harsh process having various combinations of detailed features. For this reason, the early stages of the design constitute the important parts of the process where the most critical decisions are taken, the concepts are developed and improved. Implementing such constraints to the process at the earlier stages gives the architect enough control over his design and sets some boundaries to the user. In the early stages of a design task, constraints may be negative, as in the case of restrictions. For example, a car engine cannot exceed the size of the space in which it fits, yet it cannot produce less than a specified power. As a design proceeds, they may become more positive and constructive.

In accordance with this objective, a two-stage model/system is introduced in the scope of this thesis where the user is included in the process from the beginning. Firstly, a pre-customization is framed in an urban level which the external inputs are used such as the number of schools, the level of income, the targeted population. And then, orientation, footprint, and the core+skeleton of the building is specified based on these inputs. After the end-user parameters are initiated by making some decisions with a drop-down menu, the best possible design is selected among the prototypes, already made by the architect. In the last section, the user can directly manipulate the selected design in both 3D and plan views by relocating the walls, adding/removing a room, or changing the floor material within the scope of the constraints.

For example, placing an element of design will show a dialog asking the user to choose between material, type, color, etc. If the user makes changes to the model, the system can check whether the instantiated product is still valid, or if another instance better meets the designer’s conditions. By doing so, architects/engineers will have a certain amount of control over the result by making the master design and determining the constraints.

Since the goal of this project has been to develop a method for architects to enter design constraints, the system will use constraint checking rather than constraint solving, as constraint solving allows no user input beyond setting the constraints. Constraint checking gives users freedom to make the design themselves and only indicates problems to them, matching the design intent. Additionally, it prevents performance problems that might arise from the combinatorial explosion of possible design solutions. In this scenario, the constraints serve more as a reminder than as the defining factor in the design.

To enable this process, contractors, sub-contractors, and even building product suppliers need a tool to express their financial, resource, or product constraints such as presented in this thesis. Furthermore, computer programs used by architects and engineers must allow interpreting these constraints. The use of constraints, particularly using BIM, makes the automated constraint checking considerably simpler. Especially constraint based software widely available as BIM tools are highly suitable for this kind of approach. In this thesis, Revit has been used as it is widely recognized and available in Turkey and because it supports collaborative design, design analysis, clash detection, construction planning, and even cost control. The proposed system hence provides the user a desire-customized and yet architecturally proper design as a final product.

5.2 Strengths of the Approach

In general, we assume that the user is well aware of their choices so that the architects do optimizations accordingly. However, neither the user nor the designer can foresee the result without getting involved in the process. Traditionally, architect makes his designs via sketches, physical or digital models and change/modify them constantly in order to come through with a proper design. Therefore, user who wants to customize his home in accordance with several certain preferences should be included in the design process simultaneously while showing him the results of his choices.

Additionally, users, most probably non-expert in architecture, are highly dependent on the perception and visualization skills of an architect. In order to set the technical limitations and to solve design-related technical problems, the architect uses some sophisticated softwares which are unmanageable by the average users. However, instead of being used only as a tool for solving problems, it is suggested in this thesis that such a customization system might be implemented, which is capable of collaborating with the user. A user-friendly software proposing alternatives to the customer would guide the user by explaining their architectural aspects with possible gains or drawbacks. Thus, user can tinker with many allowable design possibilities. This also means that architects can have a greater degree of confidence in how the building complies with the building code. Additionally, housing projects in which mass customization is used frees the architect from focusing on basic constraints alone to spend more time on the aesthetics and higher level goals of the design.

Checking constraints from different domains currently requires opening the design in multiple programs. Aside from the risk of incorrect results caused by flaws in the importers, this is a very laborious process. When a violation is discovered the designer will have to go back to the CAD application, go to the location of the problem, fix it, re-export the file, check it again. By not having to switch applications, it is possible to get real-time feedback on the design. The cycle required to fix problems and re-check the design becomes much shorter.

"BIM has many advantages over the classical line based method of representation. It offers an increased convenience in creation and modification, since architects can work on the element level rather than having to manipulate individual lines" (Niemeijer, 2011). Because the design contains actual building elements rather than a series of lines that can only be understood by humans, it becomes possible to automatically check whether those elements meet certain criteria. An example of this method of constraint handling can be found in softwares such as Revit and Navisworks. To show that the constraint checking in the building industry is possible, this research uses Revit, with its automatic checking for the unwanted intersection of elements in the 3D model. Navisworks, although not used here, can be a supporting software designed in order to highlight the clash detections.

5.3 Limitations, Applications and Future Research

Creating a constraint-based architectural design system comes with many technical challenges. Because of the time limits in this study, the creation of a user interface and the development of a BIM that is detailed enough to contain all the building elements has not been realized. Instead, the potential is explored for a system while specifying architectural constraints on building designs, specifically for use in mass customization. This provided a framework ratherthan a product. Certainly, the present thesis should not be viewed as trying to develop the ultimate definition of a term as complex and multidimensional as mass customization but more as one additional step in the direction of better understanding the nature and the future of this concept.

Furthermore, the choice software Revit is limited to geometrical constraints only such as specifying boundaries on lengths and distances between elements, but several other constraints exist in the construction industry and their sub-disciplines. Other types of constraints, such as those on materials or building physics, are not yet supported. Additionally, constraints are mostly specified graphically or through entering values in predefined constraints, which somewhat limits the flexibility of the system. Despite these limitations, it is a milestone on the way to bringing constraints into the building industry since it marks the first time that automated constraint checking has been available to a large group of architects. In the scope of this thesis, I can enter and test constraints while investigating their properties and general usages. The future intention will be searching the other usability of constraints indirectly by using the tool. For instance, materials science would be a good example for the fields where there are several constraints which vary depending on the application.

Finally, the limitation of the customization and the sustainability of the end product should be discussed in detail. In the daily usage, people choose houses based on some criteria, *e.g.* with a central heating system, a nice garage or a backyard, which after all, somehow become “standards” known for everyone. Similarly, all novelties in the design may end up being popular one day and may become standards known for everyone in the future. From this point of view, this customization system can also form a platform to the users to communicate and share ideas. In this way, any piece of customization done by an average user can be read and evaluated by another average user. Therefore, the system can be used as a pool where selected pieces are collected to help other users and guide future designs.

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