THE REPUBLIC OF TURKEY
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ADAPTING VERNACULAR WOOD TECTONICS TO CONTEMPORARY ARCHITECTURE VIA PARAMETRIC MODELING: BOSNIA AND HERZEGOVINA CASE

Master's Thesis

AZRA MESIC KUMRU

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This is to certify that we have read this thesis and we find it fully adequate in scope, quality and content, as a thesis for the degree of Master of Architecture.

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ISTANBUL, 2017 AZRA MESIC KUMRU

ABSTRACT

ADAPTING VERNACULAR WOOD TECTONICS TO CONTEMPORARY ARCHITECTURE VIA PARAMETRIC MODELING: BOSNIA AND HERZEGOVINA CASE

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Master of Architecture

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One of the most influential tools in the digital age is parametric design and modeling, where in the search of form finding, all inputs are interrelated via mathematical relationships to an initial geometry, and final outputs are configured according to these variables in the function. Depending on various parameters defined, any form including Euclidean geometries, complex forms and NURBS (Non-uniform rational B-spline) surfaces etc., can be modeled and transformed in a flexible way. Parametric modeling and algorithmic design software such as; Rhinoceros, Grasshopper, Maya etc. let designers visualize and experiment through a range of design variables and inputs. Hence, they are practical digital tools for creating complex structures and systems.

Since1980's, new digital design tools and fabrication techniques have been creating new technical and formal possibilities for vernacular materials. This research examines the vernacular wood crafts in Bosnia and Herzegovina in different scales of design including city planning, architecture, interior design and decorative arts. The investigation of wood as a vernacular material is then followed by as a case study, which aims to replace the concrete roof of the Old Train Station in Sarajevo with a new one inspired by wooden vernacular architecture. The proposed model employs a parametric approach which analyzes the existing form with mathematical equations and redefines it as a set of algorithms and parameters to model alternatives. The parametric model is defined in Grasshopper and rendered in Rhinoceros, hence the final form can constantly be interacted along its distinct coordinate axes and according to changing parameters. The build ability of the output structure and structural elements are then discussed and schematized regarding the existing wood joints from the vernacular architecture.
In the final part, the limitations of wood as a material and the constraints of the model are discussed together with the potentials of parametric modeling in conveying the tectonics of vernacular materials and structures to contemporary design research and practice.

Keywords: Parametric Roof Design, Algorithms, Wood Tectonics, Wooden Vernacular Architecture in Bosnia and Herzegovina

ÖZET

PARAMETRİK MODELLEME YÖNTEMİ İLE GELENEKSEL AHŞAP TEKNOTİK DİLİ ÇAĞDAŞ MİMARİYE UYARLAMA BOSNA HERSEK ÖRNEĞİ

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Dijital çağın en etkili araçlarından biri parametrik tasarım ve modelleme olup, form bulma araştırmasında tüm girdilerin matematiksel ilişkiler yoluyla başlangıç geometrisiyle ilişki kurmasına ve nihai fonksiyonun bu değişkenlere göre yapılandırılmasına dayanmaktadır. Tanımlanan çeşitli parametrelere bağlı olarak, Öklid geometrileri, karmaşık formlar ve NURBS (Düzensiz rasyonel B-spline) yüzeyler vb. modellenerek esnek bir şekilde dönüştürülebilir. Rhinoceros, Grasshopper, Maya gibi parametrik modelleme yazılımları diğer adıyla algoritmik tasarım yazılımları, tasarımcıların bir dizi tasarım değişkenleri ve girdileri formlar üzerinde görselleştirmelerini ve etkilerini test etmelerini sağlar. Bu nedenle, karmaşık yapılar ve sistemleri oluşturmak için pratik dijital araçlardır.

1980'lerden beri, yeni dijital tasarım araçları ve üretim teknikleri, geleneksel malzemeler için yeni teknik ve biçimsel olanaklar yaratmaktadır. Bu araştırma, şehir planlaması, mimari, iç mekan tasarımı ve dekoratif sanatlar da dahil olmak üzere farklı tasarım ölçeklerinde Bosna-Hersek'teki eski el sanatlarını inceler. Ahşabın malzemesi olarak ahşabın araştırılması, Saraybosna'daki Eski Tren İstasyonu'nun beton tavanı ile ahşap geleneksel mimariden esinlenerek yenilenmeyi amaçlayan bir vaka çalışması olarak izlenmektedir. Önerilen model, mevcut formu matematik denklemleriyle analiz eden ve alternatifleri modellemek için bir dizi algoritma ve parametre olarak yeniden tanımlayan bir parametrik yaklaşımı kullanmaktadır. Parametrik model Grasshopper 'da tanımlanır ve Rhinoceros ile işlenir, bu nedenle son form sürekli koordinat eksenleri boyunca ve değişen parametrelere göre etkileşime girebilir. Çıktı yapısının ve yapısal öğelerin tasarımı, daha sonra, geleneksel mimaride mevcut ahşap birleştirmelerle ilgili olarak tartışılmakta ve şematize edilmektedir.

Son bölümde, ahşabın bir malzeme olarak kısıtlılıkları ve modelin kısıtlamaları, yerel malzemeler ve yapıların tektoniği çağdaş tasarım araştırma ve uygulamasına taşınmasında parametrik modellemenin potansiyelleri ile birlikte ele alınmaktadır.

Anahtar Kelimeler: Parametrik Çatı Tasarımı, Algoritmalar, Ahşap Tektoniği, Bosna Hersek, Geleneksel Ahşap Mimarisi

CONTENTS

TABLES

FIGURES

ABBREVIATIONS

B&H	:	Bosnia and Herzegovina
CAD	:	Computer Aided Design
CAAD	:	Computer Aided Architectural Design
CNC	:	Computer Numerical Control (CNC)
Glulam	:	Glued Laminated Timber
MCAD	:	Mechanical Computer Aided Design

1. INTRODUCTION

During the last twenty years, architectural programs have become extremely prevalent in the field of architecture and design. Wood tectonics and organic architecture, promoting interaction between humans and nature, has always been an indispensable part of the vernacular architecture in B&H. The history of organic architecture and use of wood in the cities of B&H relate back to XII up to XV century. The Bosnian wooden architecture was first noticed in the medieval period and the Ottoman Empire, whereas the Austro-Hungarian period brought some differences. There are many remains of medieval fortified cities such as the Old City of Ljubuski, the Old City of Blagaj, the Old City of Pocitelj, the medieval City of Travnik, the fortress Jajce, the fortress Tesanj, etc., where combination of wood and masonry has created a harmonious architecture within the natural environment. Wood, being one of the most popular materials was completely replaced by concrete through the aggressive modernistic approach in the Austro-Hungarian (1878-1918) and Yugoslavian periods (1918-1990) (Figure 1.1). The Bosnian conflict (1992-1995) destroyed most of its historic architecture and brought destruction and rebuilding practices afterwards.

Figure 1.1: Architecture in a) Ottoman b) Austro-Hungarian c) Yugoslavian period

Source : http://www.bosnjaci.net/prilog.php?pid=18752

With the development of economy in B&H, wood entrepreneurship area started to develop rapidly in recent years. Despite the natural resources and large timber industry in

B&H, technical innovation in the area of fabrication in the construction field is quite undeveloped. Computer technology has been growing due to different needs and idea developments, which resulted in advanced new programs which provide a broad range of parametric tools to facilitate designer's further drawing.

According to Barrios (2004), by the raising up of demand tools for Computer Aided Design (CAD), in order to simplify the variations for design the Parametric Design is becoming conventional for Computer Aided Architectural Design (CAAD). Indeed, recently, parametric design has been seen as an expensive and complex software which has purpose only for high level industries. However, in order to corporate rapidly, incorporation of parametric modelling has been obligated to use standard tools in traditional CAD programs. Parametric modeling is described as one of the most powerful tools for design nowadays for bringing many opportunities in dealing with the complexity of forms. On the other hand, wood is considered as a high-tech building material in the world. Advantages as sustainability, durability, and numerous other beneficial effects which wood offers have increased its use in projects. The recent digital development in wood production, i.e. the use of diverse machines, has shown that working with wood material is easy and rapid, in both larger and smaller scales. Recently, in B&H, glued laminated timber or glulam offers big economical, creative, and sustainable potentials for design with wood.

According to Skrbic (2016), glued laminated timber is highly innovative material which is stronger than steel. CNC production and Laser Cutter make complex geometries by using glulam material and placing wood as a primary construction material. Figure 1.2 compares traditional hand craftsmanship to contemporary fabrication. Starting from the 18th century, industrial revolution has made a huge decline over traditional craft practices and has dominated machine manufacturing. However, nowadays architects and designers are steering to develop new crafts and aesthetic works via geometric computer modeling and machine work. According to Deplazes (2005), there are many new opportunities in design and production of wood material, hence engineering solutions are changing. Indeed, the use of grid system for timber production is receding its relevance, hence the wooden panel is now swapping the bar as most multilateral construction segment.

Related to the changes in the digital form, new tectonics of materials and detailing have become the crucial issues of digital fabrication.

Figure 1.2: Traditional craftsmanship in Dubai, CNC router for woodworking

Source: http://www.decoartdubai.com/Interior/craftsmanship/

After the introduction part, the second chapter of this thesis will be focusing on vernacular wood crafts in B&H: Despite the Bosnian war which occurred between 1992 and 1996, several examples of vernacular wood architecture have been preserved in B&H, especially in rural areas. These are mostly private houses, built by their owners out of locally available materials. Diversity of their forms and building materials are inspiring contemporary architects and designers. Such as the Project Hotel Pino Nature at Trebevic, Sarajevo, which was nominated for the European Union for Contemporary Architecture Mies van der Rohe award in 2017. Today in Sarajevo: three main architectural styles can be observed: Ottoman, Austro-Hungarian, and Yugoslavian. This thesis is inspired by the Ottoman and former medieval period which share a common philosophy in organic architecture: using locally available materials, specifically wood.

Figure 1.3: Contemporary Architecture in Sarajevo, Hotel Pino

Source: http://www.pino-hotel.com/en/about-us https://goo.gl/LtC9Rw

The third chapter, explains parametric design and modelling for digital form finding: Parametric design tools can be specifically tailored to specific materials and their properties. This part of the thesis highlights the wood industry in B&H through the scope of contemporary architecture (Figure1.3). Understanding how parametric architecture is affecting and increasing the concept design progresses requisite research on different topics.

The fourth part of the thesis, is a case study about the parametric model of a wooden roof at the Train Station in Sarajevo, influenced by the vernacular wood tectonics in B&H. The fifth part discusses model outcomes and concludes with the potentials of digital design and fabrication technologies in the reinterpretation of local traditional skills and construction techniques.

1.1 AIM

This research aims to highlight the potential for interpreting vernacular architecture and representing innovative design ideas. Literature research will cover wood crafts in Bosnia and Herzegovina through several wooden practices of city planning, architecture, interior design and decorative arts. Wooden elements of Iplidzik Sinan Mosque are the main source for abstraction of segments which will assemble a new roof model. The case study will be proposing the implementation of vernacular wood tectonics to a contemporary wooden roof design via parametric modelling. To progress and develop the structural system of Iplidzik Sinan Mosque, one of the formal elements has been taken and analyzed. Proposed work flow for the Train Station in Sarajevo regarding the new roof structure will be based on a code, written in Grasshopper and visualized in Rhinoceros.

1.2 METHODS

The starting point of this thesis work is related to wooden tectonics, organic architecture and vernacular architecture of B&H. Wooden tectonics are very significant for the vernacular architecture of B&H. A major advantage for this thesis has been a visit to B&H in order to investigate the sources which could not be accessed via online resources.

Another major advantage was the ability to visit the buildings and places of high significance for further work of this thesis. Diverse examples of wooden tectonics are proposed and analyzed throughout this study. The case study, Train Station in Sarajevo, has been chosen for modelling a new roof construction. The main disadvantage related to the approach and gaining information about Train Station in Sarajevo was the prohibition of taking photographs of the interior area of the station. However, data were collected with the permission of the staff at the passenger service office, and for purpose of the thesis analysis and evaluation. The design and inspiration elements for the development of the new roof model, were based on the analysis of Iplidzik Sinan Mosque in Sarajevo. The reason for selecting wooden elements of the mosque was its historical and cultural value together with their tectonic quality in design. In order to develop a parametric geometry and create a code for new roof model, due to diverse possibilities of software Grasshopper and Rhinoceros were approached in this thesis.

1.3 MODELING

For parametric modeling the most prevalent software of Rhinoceros and Grasshopper is employed. Indeed, these two types of software are offering much faster and geometrically representative way of programming for architects and designers. In addition, these two software are available as open resources with altered functions and purposes.

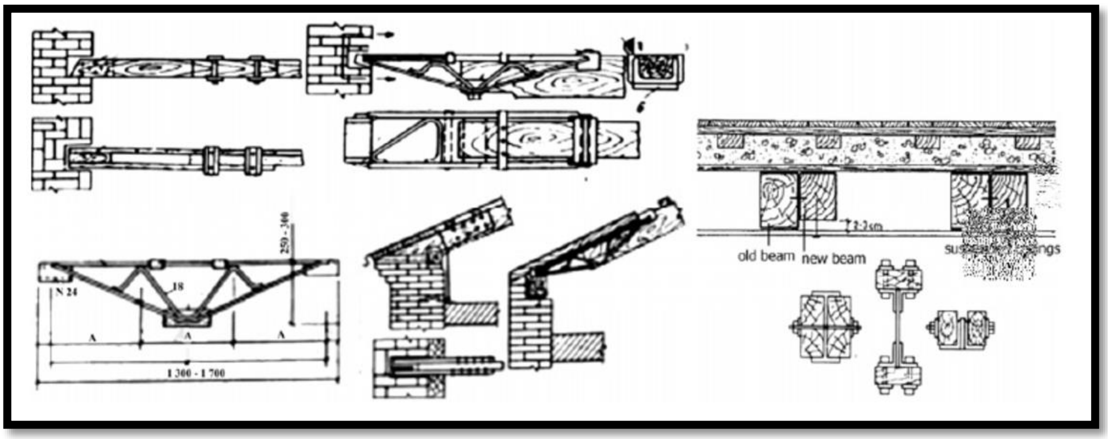
2.WOOD TECTONICS IN BOSNIA AND HERZEGOVINA'S ARCHITECTURE

The history of organic architecture and use of wood in the cities of B&H relate back to XII up to XV century. According to Foreign Investment Promotion Agency (2011), the best known natural resource in this country is wood which is covering 53% of the area. Wood tectonics and organic architecture, promoting interaction between humans and nature, has always been an indispensable part of vernacular architecture in B&H. Initially termed by Wright (1953), organic architecture strived to unify space, to blend interiors and exteriors, and create a built environment not separate or dominant from nature but as a unified whole. Vernacular architecture was well integrated into its specific environment characterized by its natural and built heritage. Ever since the middle of the 19th century, in the region of B&H, a long tradition of forestry and wood production has continuously been interpreted through different architectural periods. Bosnian wooden architecture was first noticed in the medieval period and the Ottoman Empire, and after the settling of Austro-Hungarians, a higher level of wood production has been practiced. More specialized woods such as walnut, cherry, oak, pine have been distributed as raw material, partial fabricates and finished products. 'Architecture can be seen as creativity of human culture and process of dwelling (Stephen, 2004)'. Therefore, this part traces wood tectonics in B&H varying in different contexts and geographical locations. It seeks for construction rules and order of compositions in traditional architecture which can inspire and guide new design and building techniques of contemporary vernacular architecture. Several examples of the medieval, the Ottoman and the Austro-Hungarian period will be introduced.

2.1 CITY PLANNING: The Medieval Cities

In medieval fortified cities, the main tendency was to provide irregular shapes which were determined by the configuration of the terrain and necessities of the society. Termed by Zoranic (2016), housing in the suburbs had better conditions for living than in fortified cities. Suburbs areas were places of minimal housing, while fortified cities were growing rapidly both in size and number. The increasing number of trade was parallel to the number of population. However, social needs for settlement were growing, hence architecture was developing more spontaneously than planned. Numerous masonry fortifications were constructed with wood components due to their tension resistance. ‘In constructing walls and during conservation works to protect fortifications in Bosnia and Herzegovina, one may notice and understand patterns and methods used when applying wooden beams (Hatulas) instead of steel bard. Hatulas were found in various dimensions and in all walls, even in the layers of double stone walls. A difference was noticed even in the size and shape of the hatula cross-sections in walls built in different periods of time. Crevices and holes, in most cases, indicate that in the past beams used to stand there. However, in comparison to masonry structures, those made of wood have been preserved in small numbers until today and are true rarities now precisely because of their high sensibility to changes in micro-climate (Causevic, 2016). According to Causevic (2008) a great number of fortifications in B&H made out of wood is in a state of deterioration. Humidity, soil, water, temperature were some of the main causes of it. Figure 2.1 is presenting additional beams to the existing ones, and the way the old beam and the new beam are placed next to each other during emendation. This progress also refers to beam reinforcing. Construction efficiency and technical solutions for the repair of some building elements is more delicate than designing new structure since some parts may not be known.

Figure 2.1: Additional wood beams to the stone masonry construction in vernacular B&H architecture



Source:http://www.rudarska.hr/index.php?view=article&id=162%3Aarhitektonskekonstrukcije&format=pdf

There are still many remains of medieval fortified cities with wood as one of the main materials through construction, such as the Old City of Ljubuski, the Old City of Blagaj, the Old City of Pocitelj, the medieval City of Travnik, the fortress Jajce, the fortress Tesanj, and the fortress Doboj.

In medieval fortifications of B&H, there was frequently one multi-story tower whose cross-section was mostly round, while later they started to design it in the rectangular shape. Indeed, there were also towers with other cross-sections as triangular and octagonal as represented in Figure 2.2. The number of towers, such as gate towers, were developed as well. Wooden structures of the medieval fortifications composit one whole together with the floor and ceiling areas. Beams and ceiling girders were the main elements of the wooden ceilings.

Figure 2.2: Tower in Pocitelj

Source: Restoring Wooden Structural Elements and Transparent Structures Protection *And Rehabilitation of Bosnian*-Herzegovinian Medieval Fortifications, Faculty of Architecture, University in Sarajevo, 2016

The earliest cities of B&H were not planned in the sense that street layouts and houses were in accordance with an overall plan of the local authority, but the Pocitelj city had already had urban plans for public spaces prior to its construction. Figure 2.3 represents the way a combination of wood and masonry creates a harmonious architecture within the natural environment of City of Pocitelj. It is presenting the ceilings, the floorings, the roof, the windows, the fences, the beams and the columns of the houses that were constructed out of wood. The integration with the nature and the use of local materials is describing this city as a blend of Mediterranean and Oriental elements with local features. Gable roofs, small and widely separated windows and interior design in single-story buildings is strongly related to the Mediterranean architecture. Oriental architecture is represented by use of hipped roofs, arrangement of rooms with hajat (anteroom), sitting areas and enclosed courtyard.

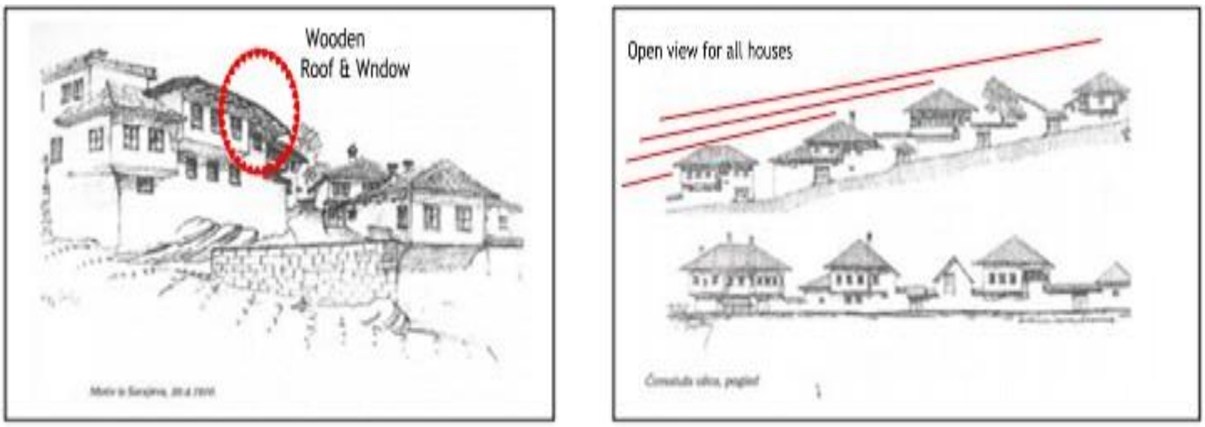
Figure 2.3: Houses of the City of Pocitelj

Source: https://goo.gl/WJnEnn http://www.narod.ba/otkrij-bih/stari-grad-pocitelj

2.1.1 Architecture: Traditional houses and structural elements

The inordinate majority of residential buildings in B&H have been built in an organic manner in terms of spatial organization, integration with the environment and use of local materials. Through different architectural periods as the Ottoman Empire and the Austro-Hungarian Empire, houses were built in different styles and used diverse structural elements and materials. According to Pasic(1998), the main factors for the varying housing typologies in different regions were climatic conditions, geological features determining characteristics of the soil and socio-economic factors. Since Bosnia and Herzegovina has always owned large amounts of forests, wood elements have always played a vital role in the design of the residential and civil buildings. Increases in trade and wealth during the Ottoman Empire caused a fast population growth, hence new urban plans were developed. Figure 2.4 represents the residential buildings which were placed above each other in such way that each house has a view. Different type of houses were following the nature and local materials in constructional sense. Due to social and economic aspect, buildings and houses were constructed much closer to each other.

Figure 2.4: Residential buildings



Source: http://beautiful-eastern-europe.blogspot.ba/2014/05/vranduk-bosnia-herzegovina.html

The Ottoman traditional house complex was described with three parts: House, avlija (yard) and garden. The external shape was characterized by exuberant facades, cubic forms, unornamented walls, open wood-paneled drawing rooms (in Bosnian, Divanhana), and wide eaves (Figure 2.5).

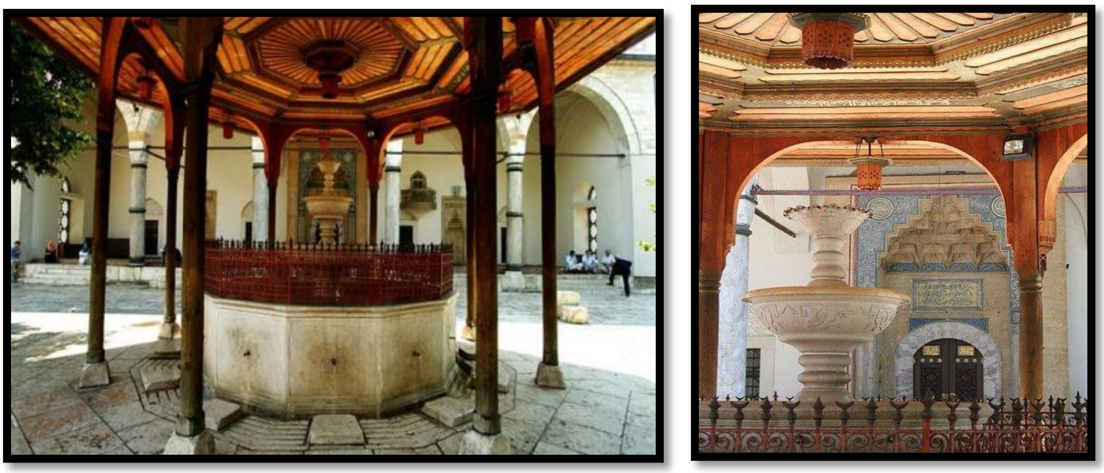
The materials most frequently used were wood, stone, and adobe brick. These materials lasted for the life of the building. Timber-frame structure supported the adobe brick, (in Bosnian, bondruk), flat ceilings and four-sided roofs. The wood structure and the wood board in roofs and ceilings had been perfected to the point of virtuosity in the unique residential architecture (Korjenic and Klaric, 2011). According to Hadrovic (2008), the favorite building material was wood. Houses exuded the smell of wood and cleanliness.

Figure 2.5: Traditional Bosnian house (Svrzo's House in Sarajevo)

Source: http://www.mygola.com/svrzo-house-p48819

However, there is a rich heritage of civil wood architecture, reflected by the authentic style of a wider domain of the Ottoman Empire. Gazi Husrev-Bey Mosque, constructed in 1532, owns a huge yard which contains a fountain with thin wooden fences and is covered by wooden construction (Figure 2.6). The roof construction has eight wooden columns joined by arches which make the whole structure connected. It is very specific due to the ornamental decoration which has been done entirely by hand. Muslim worshippers use the fountain before praying, hence the fountain is still in constant use.

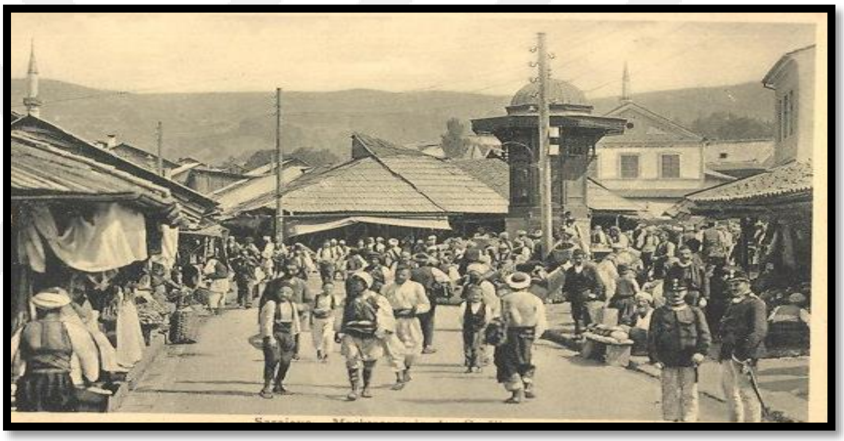
Figure 2.6: Wooden fountains - Gazi Husrev-Bey Mosque



Source: http://sbk.eu.com/izdvojeno/gazija-s-pesteri-koji-je-paris-zamijenio-igmanom/

Stated by Celebija (1660-1680), until 1660, in Sarajevo there were three hundred fountains like the one at Bascarsija Square, which is the only remaining one and was constructed in 1753 (Figure 2.7). Water pipes were placed from Gazi Husrev-Bey area to this square. The fountain had a stone structure but the exterior part was made out of wood. The wooden part was designed and crafted by different oriental elements such as small quadrants, sharp endings and many soft surfaces. This fountain was demolished during the fireworks in 1891. A new fountain was constructed based on a project of Witek in 1913 and it still exists in Sarajevo (Figure 2.8). It has same wood elements which were crafted on the old structure as well as the structural form.

Figure 2.7 Bascarsija square during the Ottoman Empire



Source: http://furaj.ba/sebilj/

**Figure 2.8: Bascarsija square a) Project of Aleksander Witek;
b) 3D representation of the fountain**

Source: https://sarajevo.co.ba/znamenitosti/sebilj-na-bascarsiji/

2.1.2 Interior design and decorative arts

During the Ottoman Empire in the interiors of traditional B&H houses, the main structural and decorative elements were made out of wood. Muslibegovic House in Figure 2.9 where the interior part has different decorations crafted on wood.

'The basic elements of wooden ceilings are wooden beams or ceiling girders. Additional elements of wooden roof structures are smaller beams or screed boards or fillings of various composition and purpose depending on the properties of floor and ceiling structures (Causevic, 2016).'

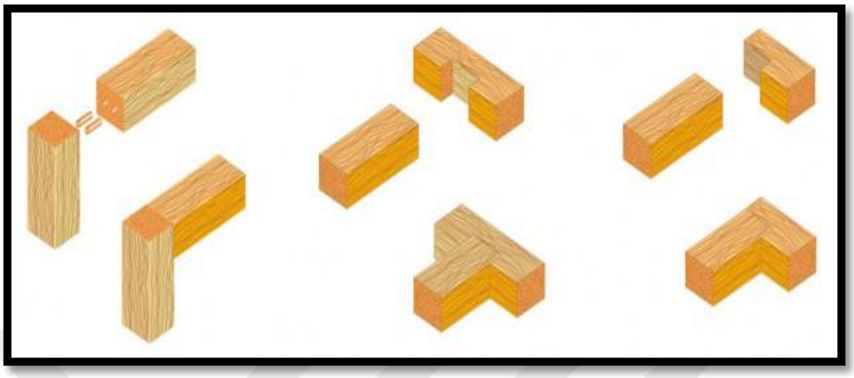
Figure 2.9: Traditional Bosnian interior, Bosnian national monument Muslibegovic House (1872), Mostar

Source: https://goo.gl/oWB4CK

Master craftsmen, inspired by the Bosnian culture and nature employed wood for diverse kind of structural elements. For decades, it has been used in structural joints, columns and beams in exterior and interior areas. Traditional way of connecting wooden beams and columns implied a proper use and insertion of wooden pins, hence later iron pins and clamps were invented. The technique of imbedding wood pin into other wooden elements has been removed from practice, due to its function and harder production (Figure 2.10). The strength and stability of wooden structures depends on the quality of their compounds and joints. According to the position of the connecting elements, there can be seen a difference between rectangular, slit, and flat joints. However, connecting elements which were later used for wooden materials were steel, wooden connectors and later wood glue.

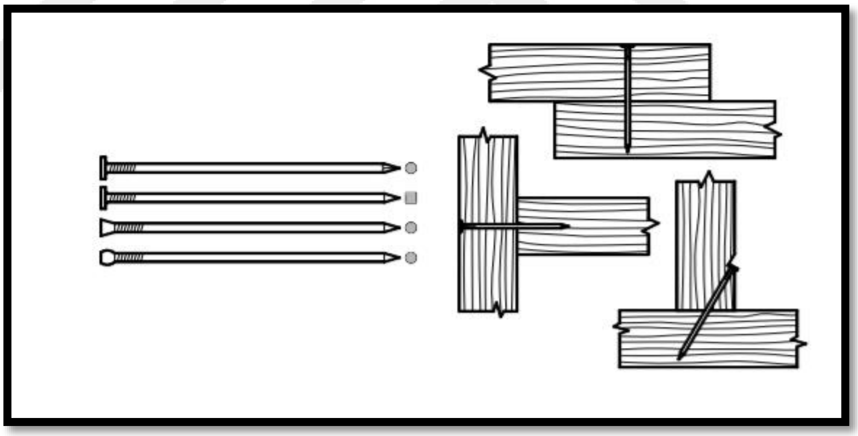
Steel materials include various types of exerts, screws, nuts, hoop plates, and jambs (Figure 2.11).

Figure 2.10: Structural joints from traditional wooden elements



Source: https://tr.scribd.com/doc/96824237/09-drvene-konstrukcije-00

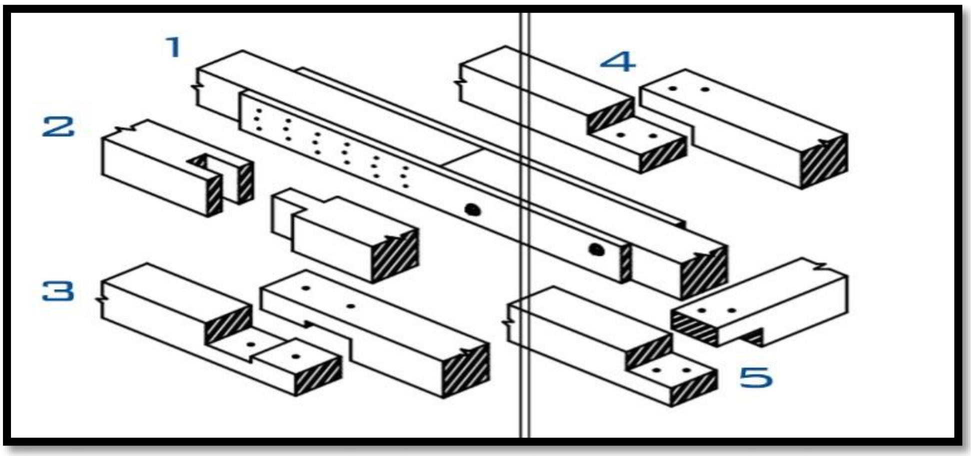
Figure 2.11: Structural joints from traditional wooden elements with the addition of steel connections



Source: https://tr.scribd.com/doc/96824237/09-drvene-konstrukcije-00

Connectors can differ according to the mode of execution, position of the connected elements and the type of the strain in elements. In comparison to the way of performing, there is difference seen between traditional implemented connectors and modern joints where various metal bond joints have been applied. According to the type of strain, there are diverse different joints such as axial pressure, axial tensile, and sintering joints. According to the position of the joint elements, there are flat joints, rectangular joints, straight joints, extension joints, and diagonal joints as represented in Figure 2.12.

Figure 2.12: 1) Flat joints, 2) Extension joints, 3) Rectangular Joints, 4) Straight joints, 5) Diagonal joints;



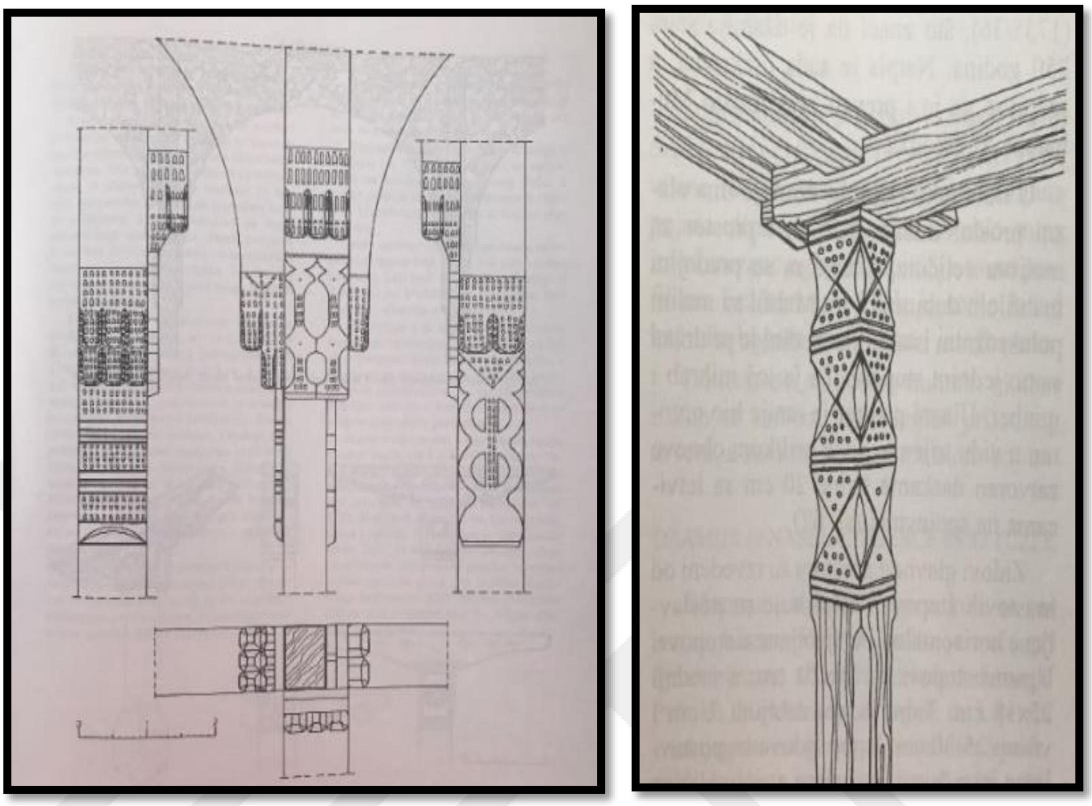
Source: https://tr.scribd.com/doc/96824237/09-drvene-konstrukcije-00

Wood has also been used in structural joints, over columns and beams in exterior and interior areas (Figure 2.13). Indeed, the main structural and decoration elements were presented by wooden beams and columns which have also had decorative segments. High quality and uniqueness of craftsmanship has been presented by decorations as represented in Figure 2.14.

Figure 2.13: Traditional Bosnian interior, wood as a structural joint, (Cana, 2016)

Source: https://aab-edu.net/assets/uploads/2016/12/01-2016-EN-04-Arta-Januzi-Cana.pdf

Figure 2.14: Details of a wooden column craved by hand, (a) Hubjar-Aga Mosque (b) Mosque in Podzvid



Source: Dzamije sa Drvenom Munarom u Bosni i Hercegovini, Becirbegovic, 1999, Sarajevo Publishing

In terms of interior design and furniture making, wood craftsmanship in B&H has gained a universal acclaim. The unique carving and furniture style known as the “Bosnian Konjic style” has entered UNESCO’s Intangible Cultural Heritage List in 2014. The technique, has been used in the making of luxury furniture since 1927. According to Niksic (2013), designers and architects of the city of Konjic are using local wood such as walnut, cherry, maple, elm, ash and oak, and they also apply modern technology further improve their design. After that, extremely skilled craftsmen apply traditional hand carving techniques on modern design furniture and thus create innovative designs. Each piece is finalized by hand with natural and environmentally friendly final coats. All products are made in limited quantities, thus two products can never be the same. It incorporates a developmental model that seeks to help reestablish Bosnia’s place in the global furniture market (Figure 2.15). It also helps to solve environmental issues of sustainability.

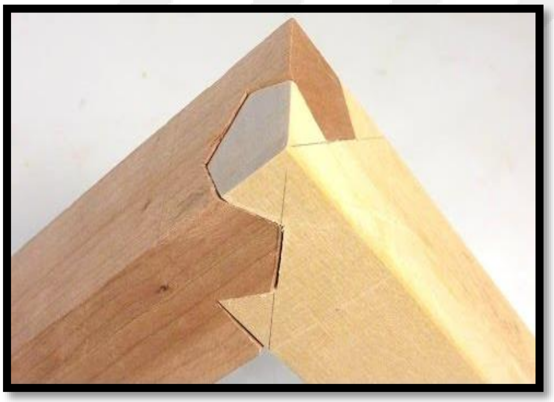
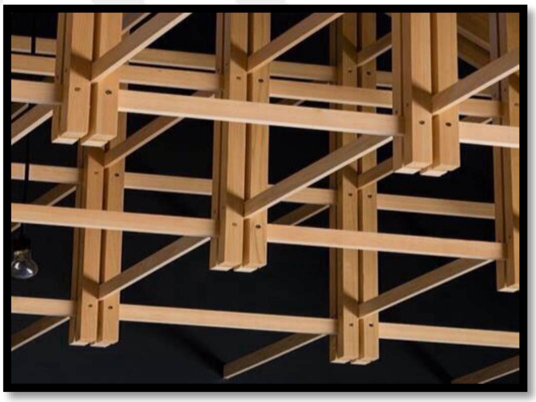
Figure 2.15: Bosnian - Konjic style in old and new furniture


Source: http://h.etf.unsa.ba/btp/content/peskun/peskun_bos/model.htm

Source: http://www.zanat.org/en/product/tattoo-stool/38

Figure 2.16 represents the use parametric design and glued laminated material with the use of joints to support long span and complex structures.

Figure 2.16: Parametric wood joints

Source: https://www.thingiverse.com/thing:1063768 https://www.pinterest.co.uk/makotoom/wood-join/

3. WOOD TECTONICS AND PARAMETRIC ARCHITECTURE

Recent technical innovations in construction and material technology require enhanced design adaptability and aesthetics. Currently, parametric design and 3D modeling is representing one of the main creative design ideas where architects and designers develop alternative types of design. This thesis seeks to explain parametric design and modelling, through examples, research studies, and techniques.

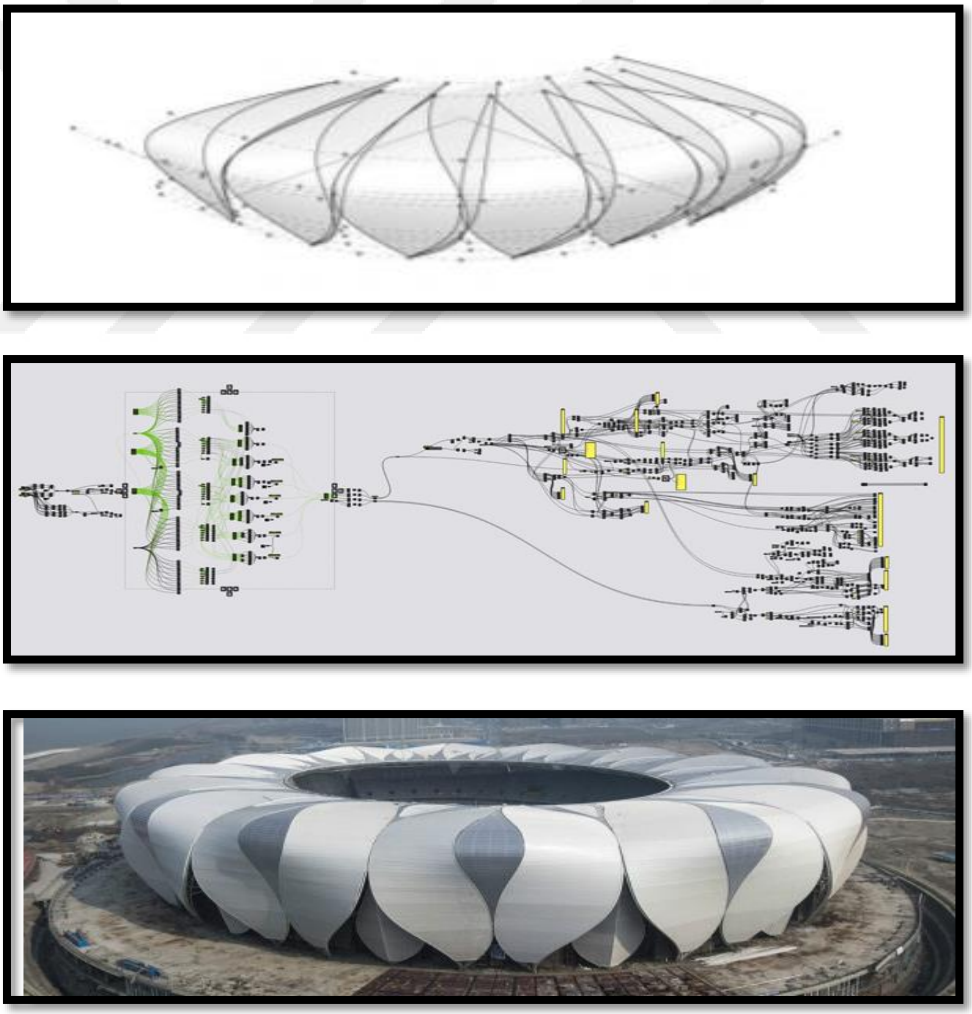
3.1 PARAMETRIC DESIGN AND MODELLING

In a parametric environment, from processor to process designer the role of the producer is changing. Terms like parametric, solid, surface and feature-based are mostly used by Machined Computer Aided Design (MCAD) modelers which are using these modelling design tools. Feature is a basic unit of a parametric solid model, it is created out of an assembly and a part file. Individual parts are make up the assembly and the part file are created out of individual elements. These individual elements are called features. The modeler is working on the whole progress through particular segments of features, hence when one of them is created, the geometric constraints are specified. All goods are then stored and during the next step the features are generated. It can be all seen as a bond of features, from old to new ones. All are depending on each other in a way that design transformation will be apprehended automatically. Indeed, all elements of features as bosses, ribs, fillets are related as a part of the model transformation hence modeling software restores that feature. There are two main types of features called sketch features and applied features. Solid model is representing topology of part and it contains volume information. *A* parametric solid model contains many features which are seen as basic units. The starting point of parametric solid modelling is a sketch, which has to have similar dimension as the feature which has been created.

Besides, digital architecture requires the consideration of both structural and environmental performances for the realization of fabrication and construction. In this sense, parametric design tools can be tailored to specific materials and their properties.

The Hangzhou Tennis Center in China (Figure 3.1) is one of the examples of parametric methodologies. The modular system of sculptural steel trusses whose function is to provide shade, was the basis of stadium envelope design. Complex geometric system of the exterior has been done by the integrated parametric system. The main stadium design was completed by the use of software Rhinoceros and Grasshopper. An algorithm has been developed at Grasshopper, where with the team of collaborators has been used to study the stadium's geometry and coordinates. A point cloud system has been defined in order to parametrically create modular system.

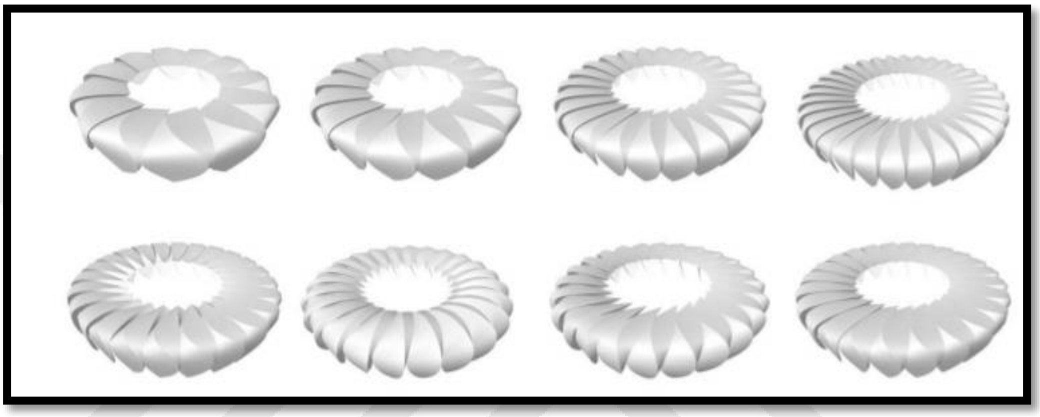
Figure 3.1: Algorithm for defining geometry for Hangzhou Tennis Center in China



Source: https://digitalprovocations.wordpress.com/2011/11/09/project-3-1a/
https://tr.pinterest.com/pin/467107792579992938/?lp=true
http://www.nbbj.com/work/hangzhou-stadium/#previous

Twenty-four truss modules are composing the exterior envelope which is a circular arc. It is a very complex and large-scale area which has a repetitive pattern that is enclosing the stadium's seating part. The main functions of the shell are to provide shade and rain protection. Within the conceptual constraints, the variations and alternatives have been allowed by the parametric definition of the exterior geometry (Figure 3.2).

Figure 3.2: Variations on the exterior envelope of Hangzhou Tennis Center in China



Source: https://digitalprovocations.wordpress.com/2011/11/09/project-3-1a/

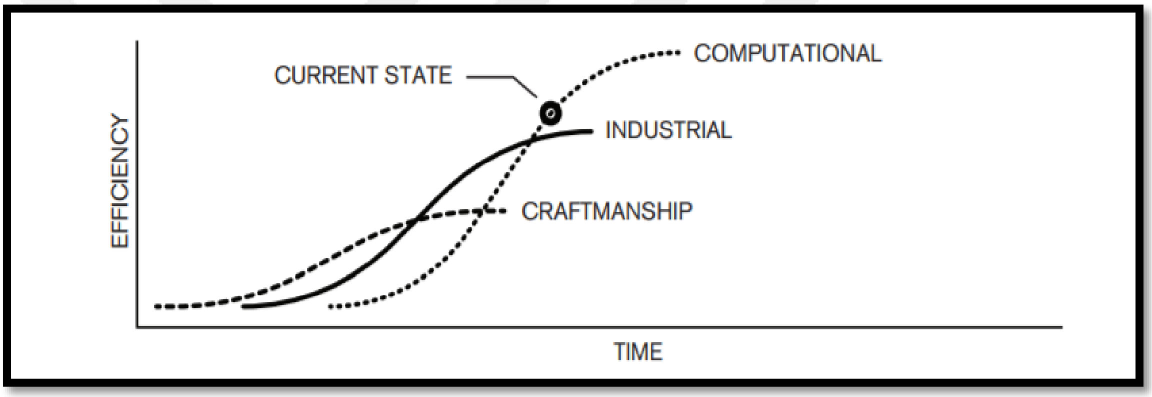
Kangaroo Physics plug-in for Grasshopper was used to simulate the effect of gravity on the truss elements. Appropriate structural adjustments on the trusses were done over this simulation. The tensile and compression forces were illustrated through this process where the structural problems at early phases were identified.

3.1.1 New craftsmanship with digital fabrication techniques

Tools available for manufacturing have always determined how wood has been used in production. By the introduction of diverse digital tools into production environment, the change could be expected in the way how wood is observed as a material. By the use of modern progress and machines, wood has been demonstrated as an easy to work with and an ideal material for the digital progress. Currently digital technologies and manufacturing process are progressing in new fabrication methods, which do not eradicate but rather improve traditional techniques. Throughout history of wooden construction three major eras can be listed according to the processing principles: *hand tool technology, machine tool technology and information tool technology* (Schindler, 2005).

Hand tool technology, meant that cut and sawn were done for a specific purpose by use of hand tools while working with timber. In the time when everything was done by hand, carpenters were in charge of planning and erecting the building. This was leading to a variation in architecture where buildings were based on tradition, knowledge and materials.

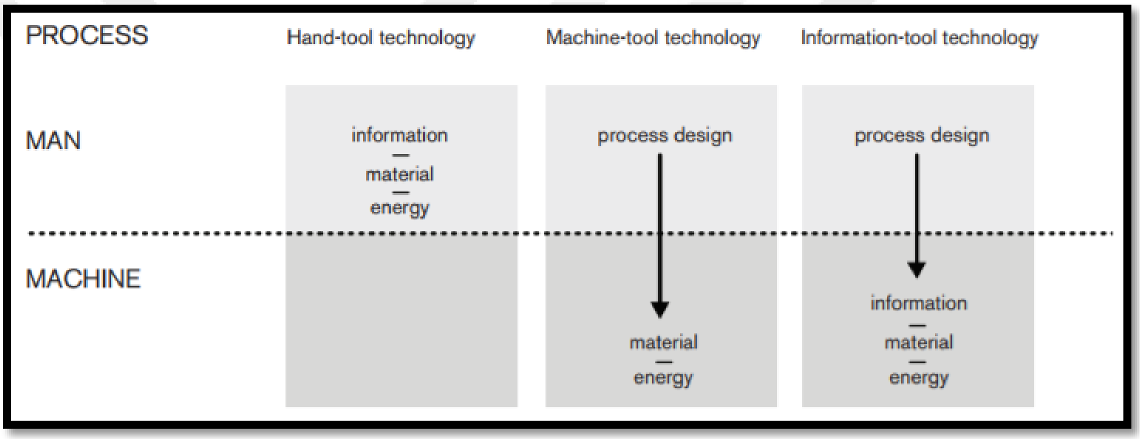
Figure 3.3: Three waves of production technology (Schindler, 2005)



Source: http://www.caad.arch.ethz.ch/wiki/uploads/Organisation/2007_Schindler_Information-tool-technology.pdf

Figure 3.3 shows the efficiency-time graphics of these three techniques. In the industrial revolution, the production time of these building components decreased and the concept of mass production was introduced, hence the efficiency increased significantly. However, machines limited the geometrical intricacy of the object parts. The wood architecture during machine tool technology era could be denoted by the prefabricated house where wooden joints were done by steel connectors. Diverse timber products and plywood were introduced to market and transformed the architecture from uniquely made to mass produced. Wood has been seen as an easy material that had the ability to be transformed for any kind of geometry and progressed into fast construction. Computational design is considered to be more efficient due to advances in construction and material technologies, which have enabled the use of freeform surfaces in contemporary structures. Architectural pioneers such as Gehry and Lynn introduced to the world the extreme forms made possible by digital fabrication. Thanks to the usage of machines controlled by computers, such as 3D printing, laser cutting, and CNC machining, it is now even possible to transfer designs made on a computer to computer-controlled machinery that creates actual building components. This "file to factory" process not only enables architects to realize projects featuring complex or double-curved geometries, but also liberates architects from a dependence on off-the-shelf building components, enabling projects of previously unimaginable complexity (Iwamoto, 2009).

Figure 3.4: The respect labor division of man and machine (Schindler, 2005)



Source: https://goo.gl/C4a7Q1

The introduction of information tool technology was made with Jacquard's weaving machine in 1801. This machine could process both material (wool), energy (steam or electricity) and information, in the form of punched hole cards. The same weaving machine could now from different cards produce different patterns. For the first time in history, "man was the creator of the process and the machine the creator of the product (Schindler, 2005)". First digitally controlled timber joinery machine appeared in 1980s. Machine had the ability to control sawing, freely cutting, assembling and milling. Indeed, new possibilities were approaching such as the production of unique pieces, instead of mass fabrication. New pieces, which were individually assembled, could be produced in the same time as ten identical ones. Hand-tool era could be similar to this approach of custom-making structural timber units. As in Figure 3.4, the process between humans and machines has been represented through the machine technology and the tool technology.

According to Kolarevic (2003), there is a valuable feedback mechanism between humans and production. In his studies, architects have always been seen as builders who are constructing buildings. In this kind of process, they found a new digital way of sending information to manufacturing and constructing buildings, where long production has been replaced.

3.2 WOOD TECTONICS IN PARAMETRIC MODELLING

A successful synthesis of technology and spatial design results in producing a good, convincing building that can both surprise and amaze us. According to Frampton (1995), the art of constructing an integral component of the design and shape using appropriate construction technology is called tectonics. It can be interpreted as construction technology's potential for artistic expression. According to Frampton (2001), architecture is more than scenography and visual—it is also tactile and tectonic. Much of what made something architectural is its physicality, its structure, its constructiveness. Nevertheless, tectonic is not the mere joining of parts, but rather, it is the artful and meaningful joining of parts, stimulating the mind and the senses. Technology is not used to only find the solution of the problem, but to create sensual experience of the space as well. There are three main factors that determine a building's tectonics: the material, the tools and the ability to work with the material, and the design. With the advancement of technology, both the processing of the material and the design process have changed. In addition, timber is continuously being improved in order to support new technical and design possibilities, especially the ones presented in the digital age which have strong tendency towards individualization, electronic control of production and design tools that can be parameterized. The need for serial production is eliminated due to the ability to control machines and whole production process with an integrated computer code. The information flow is variable as well, meaning that components of various shapes can be produced without time loss in the production process. The easy machinability of wood makes it a perfect material for digital processing, and therefore, it is taking on the status of being a high-tech material. With the changes in production process, the new model of the building had to be introduced as well. Parametric models make it possible to change building form and components without drawing everything all over again. In case the form is changed, the components are simply adjusted to fit the newly presented shape.

Instead of the form being drawn, in a parametric model, the process generates the form and its belonging components. It is important to evaluate parameters that control the process in order to make adjustable form. Natural wood, efficient and standardized, is becoming more used and important in the tectonics. The properties of wood, such as its easy machinability, low weight and surface structure, contribute to its admiration, and make timber more attractive and useful in both digital production and interior design.

"The tectonic remains to us today as a potential means for distilling play between material, craftwork and gravity, so as to yield a component which is in fact a condensation of the entire structure (Frampton, 1981)." When materiality is related to the culture of building, Scarpa's works are found to be inspiring. The emphasis he placed on the joint, and the montage technique he used in its implementation, brought a new insight towards the tectonic culture in architecture (Figure 3.5). The digital architecture requires the consideration of both structural and environmental performances for the realization of fabrication and construction. In this sense, parametric design tools can be tailored to specific materials and their properties.

Figure 3.5: Carlo Scarpa Wood Joints; *a)* Wooden railing corner joint; b) Olivetti Showroom, Venice, Italy, 1957-58

Source: https://tr.pinterest.com

As an example of wood tectonics in parametric design, Metropol Parasol Seville which is the new contemporary urban center and the world's largest wooden construction that opened in spring 2011. The main goal of the architect Mayer H. (2004) was to redevelop the city square and design a bond between the historical medieval city historical medieval city and the contemporary city. Realized as one of the most innovative bonded timber structures, 120 meter long and 45 meter wide timber structure explores a place of an elevated plaza, restaurants, farmers market and panorama terrace on the very top of the parasols. It has more than 3000 connection nodes on the top part and 11000 moment resisting connections placed over the top and bottom. The structure consists of six interlocking wood trees or 'mushrooms', which are creating organic shapes and design (Figure 3.6). Steel structure is also employed for very high platforms and construction of a restaurant and a bridge over the main road.

Figure 3.6: 'Mushroom' structure of Metropol Parasol Seville, 2011

Source: https://goo.gl/fe7btg

3.3 WOOD INDUSTRY IN B&H

As mentioned in previous sections, wooden tectonics have a high potential for vernacular B&H architecture. At the region of the Western Balkans, B&H has the largest share of forests with a very high amount of diverse types of forest. Long tradition and good international cooperation in wood production brought B&H to start with more complex manufacture and design. The primary sector of production of wood is working with lumber and wooden panels. In the region, B&H is the leading country in the export of timber, wooden panels, and furniture. From traditional business of manufacturing until the modern production and use of diverse machines, this country has a very strong wood sector. The necessity for new materials is rising rapidly, hence one of the most prevalent materials is glued laminated timber or glulam.

Glulam is a highly innovate material which is stronger than steel. In B&H, its production became very common and varies from simple to very complex and curved forms. It is used in both commercial and residential construction. Since glulam is allowing much longer length, application is possible on diverse structural elements such as beams, columns, wall studs and roof panels (Figure 3.7).

Figure 3.7: Glued laminated material

Source: http://www.mlinoles.com/index.php

Glulam has improved physical characteristics than massive wood and better flexibility for application and shaping (Table 3.1). High aesthetic quality of glulam allows the structural elements to be visible therefore giving them enhanced visual characteristics. The production of glulam have appeared proven to be profitable, hence a lot of cities in B&H are working in this domain.

Table 3.1: Basic Technical Information of Glulam

1. Adhesion: Melamine resin-based adhesive
2. Density: Approx. 550 kg / m³
3. Width: 70 to 220 cm
4. Height: 80 to 1000 cm
5. Length: 2 to 55 m, standard size 5 m
6. Lamella thickness: 10/ 22/ 32/ 42 mm

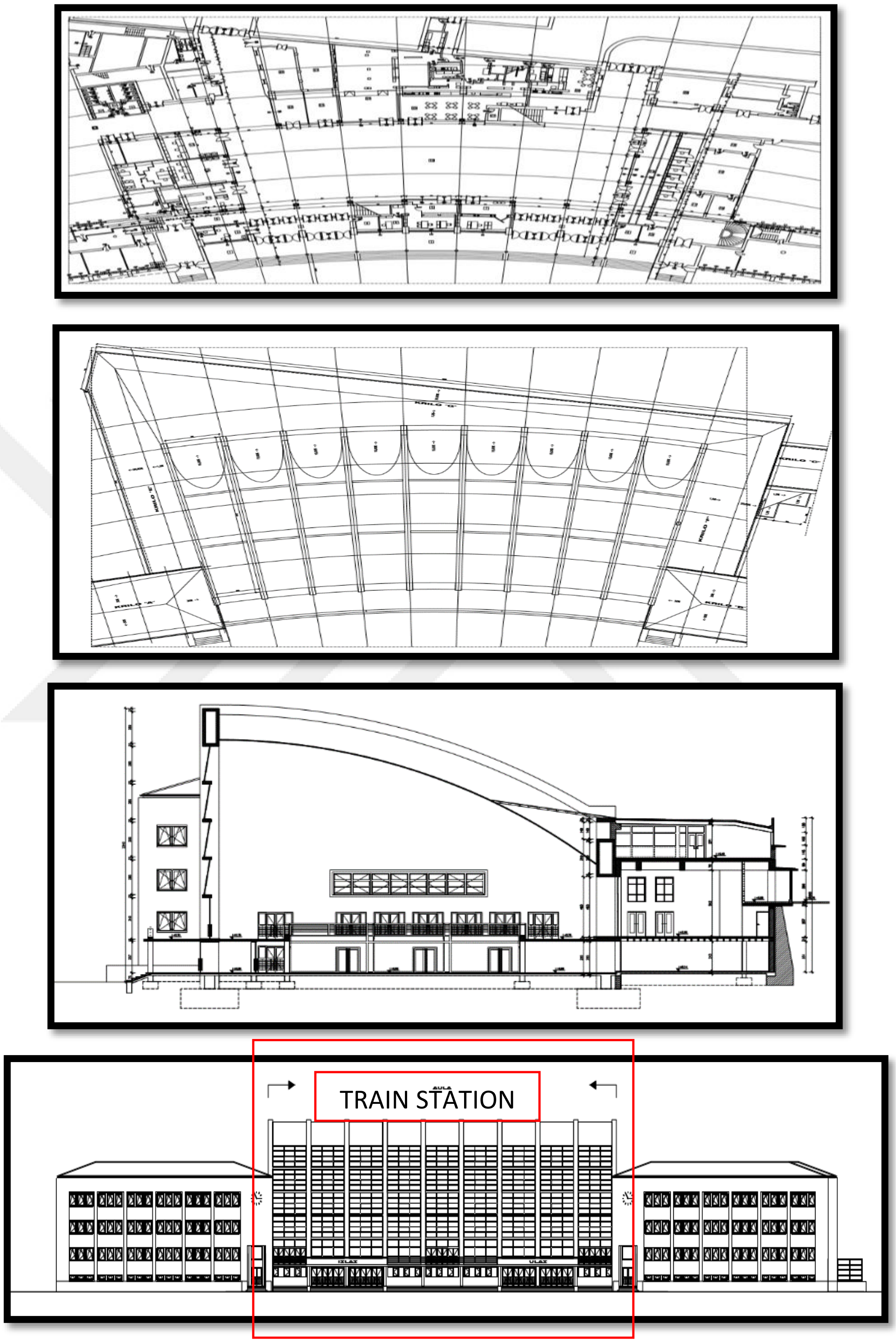
4. CASE STUDY

The train station in Sarajevo was inaugurated in 1952. Czech architects Hacar and Novacek set out the design and development of the construction. The initial project was ambitious, being a strong demonstration of superiority of engineering spirit. Design, construction and technical ideas for the station and rails were representing Czech and German architects to the public. Later due to political issues and problems, Czech architects were retreated out of the project. The rest was completed by the architect Stojkov. During Federal Republic of Yugoslavia, the train station in Sarajevo was the biggest and the most modern within the borders. It had large waiting areas together with restaurants, cafés and other activities such as conference rooms and VIP halls.

Figure 4.1 represents the main plans and sections about the existing Train Station in Sarajevo. The Bosnian architect Velimirovic (1998) refers to its paraboloids geometry, "In the constructional sense, it is a thin shell of a great bearing capacity and wide usability in spatial structures, either as a complete form or in parts. In the mathematical sense, it is treated as a geometrical surface on which it is possible to determine the rotation field and the field of infinitesimal deformations, and it is rigid." According to Velimirovic (1998) paraboloids were constructed in order to replace simple and express complex spatial-surface systems.

Indeed, the most influential asset of the Train Station in Sarajevo is its structure. The top is covered with nine radial hyperbolic paraboloids, spanning 30 m, width 6m-7m, and depth 5m. Attractive thin shell structures called paraboloids were constructed during the middle of the 20th century by the Spanish architect Felix Candela.

Figure 4.1: Train Station in Sarajevo, Ground Floor Plan, Roof Plan, and Section



Source: Prof. Dr. sci Fejzic archive, d.i.a, Sarajevo,2003

Unfortunately, the building, the plaza and the roof paraboloids were devastated during the period of 1992-1995, also known as the war years in B&H, and were not in use for a long time (Figure 4.2). The building and the roof structure were destroyed over many parts; there were no windows, doors or the facades left. The interior part where the paraboloids were placed, the entire surface has been devastated by bombs as represented in Figure 4.2. The material used for hyperbolic paraboloids was wood.

Figure 4.2: Train Station after the war, 1996.

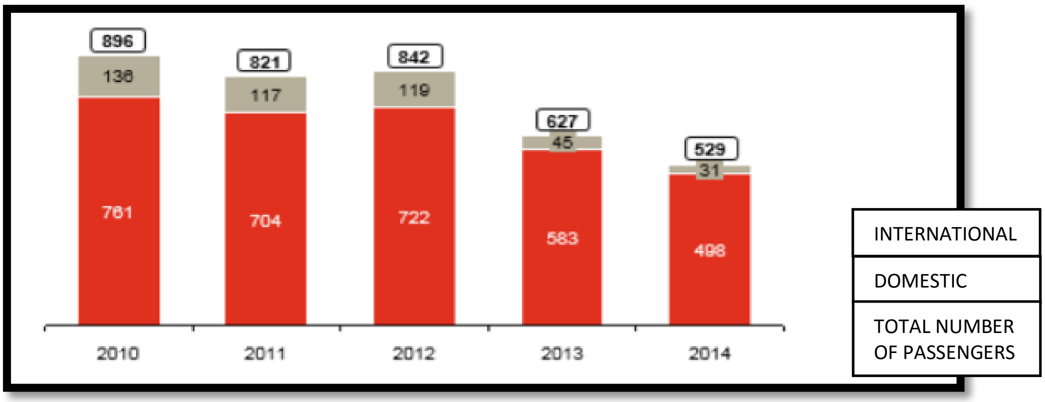
Source: https://goo.gl/5zcihN https://goo.gl/oSW1uX

Being one of the most important monuments with the most specific structure and design in B&H between 1953 and 1992, after war the train station required a new functional and spatial organization. The first major reconstruction took place in 2000. However, due to the lack of financial resources, it was only possible to fix the facade and openings on the south facade of the main auditorium. Hyperbolic paraboloids were left in a damaged state. After 2003, the government decided to repair paraboloids but not to keep the original material. The concrete material was applied over the surface, therefore wood was replaced as represented in Figure 4.3.

Figure 4.3: Train Station in Sarajevo, B&H, 2017

Firstly, the quality of the station and the way passengers experience it can contribute to the daily amount of travellers and visitors. However, current station in Sarajevo does not offer a pleasant and suave environment. Within the interior which appears to be cold, the station does not have much to offer to its passengers. What is missing are places like sitting and resting areas, as well as activity places. The main factor affects the station's needs is the economy of B&H there is lack of investments in this domain. Secondly, the geographic location of the station has an influence on travel demands. Indeed, Sarajevo Train Station can be identified as a strong bond between important cities. Unfortunately, passengers from international and domestic areas have been travelling by train less and less in the last couple of years as represented in Figure 4.4.

Figure 4.4: International and domestic chart representation of passengers at Sarajevo Train Station from 2010.-2014.



Source: http://www.mkt.gov.ba/aktivnosti/default.aspx?id=5029&langTag=bs-BA

In order to protect the heritage buildings of the Bosnian vernacular architecture such as the Train Station in Sarajevo, vernacular materials and their tectonics can be retailored with digital design and production. As discussed in the Section 3.3, B&H has a high potential of wood production and technology such as glulam. Therefore the case study is to design a new roof with a parametric structure by using the material glulam, which can span long distances. This would gain a new design perspective to the city, as well as a high economic contribution for the country.

4.1 CONCEPT

Ricoeur (1965) states; "It is a fact: every culture cannot sustain and absorb the shock of modern civilization. There is the paradox: how to become modern and to return to sources; how to revive an old, dormant civilization and take part in universal civilization". This thesis is focused on the parametric design in an early design phase. It aims to highlight the potential of wood tectonics for contemporary B&H architecture by using the methodology described below:

i) Design a parametric roof structure
ii) Use of Grasshopper and Rhinoceros for modeling
iii) Provide a Grasshopper Code
iv) Create a mock-up model with CNC machine
v) Analyse interlocking parts for analysis of joints and adapt traditional elements

4.2 ABSTRACTION

The parametric model is configured with compositional rules drawn from vernacular wood architecture. It requires initial geometric abstraction and therefore refers to standard elements of the wood architecture in B&H. Through investigation on vernacular wood tectonics, several examples of traditional wood elements have been represented in this thesis, however only one has been used as an inspiration for the new roof proposal (Figure 4.5).

Figure 4.5: Jekovac Iplidzik Sinan Mosque, Sarajevo, B&H, 1521.

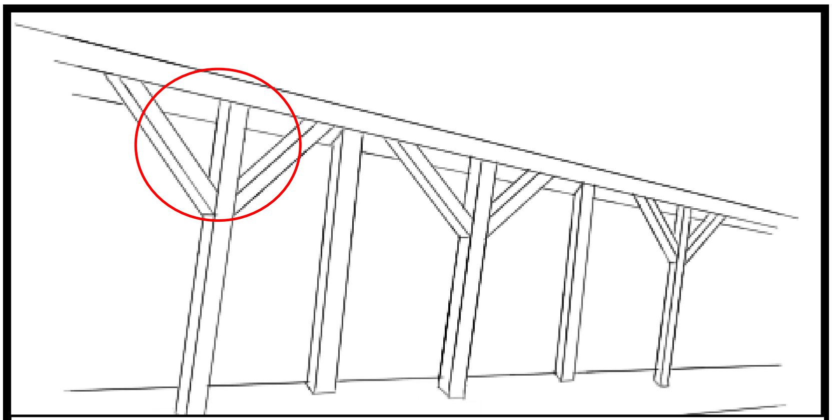
Source: https://goo.gl/Hy3f7B

The whole process of finding a suitable segment of the mosque is based on the initial materials, production methods, and the system related to the parametric structure that was used later. To develop and understand the structural system, one shape has to be taken and analyzed in order to be developed and evaluated. Wooden elements and joints in Iplidzik Sinan Mosque are the main source for abstraction of segments which enable the new roof proposal. As represented in Figure 4.6, there were beams and columns made out of wood in the 16th century.

The main purpose of these elements was to support the structure of the Iplidzik Mosque, as well as for the external appearance. The design of the system and form started by using these shapes from the mosque, which were interlacing. The main joint elements were wooden, without any additional elements from other materials (Figure 4.7).

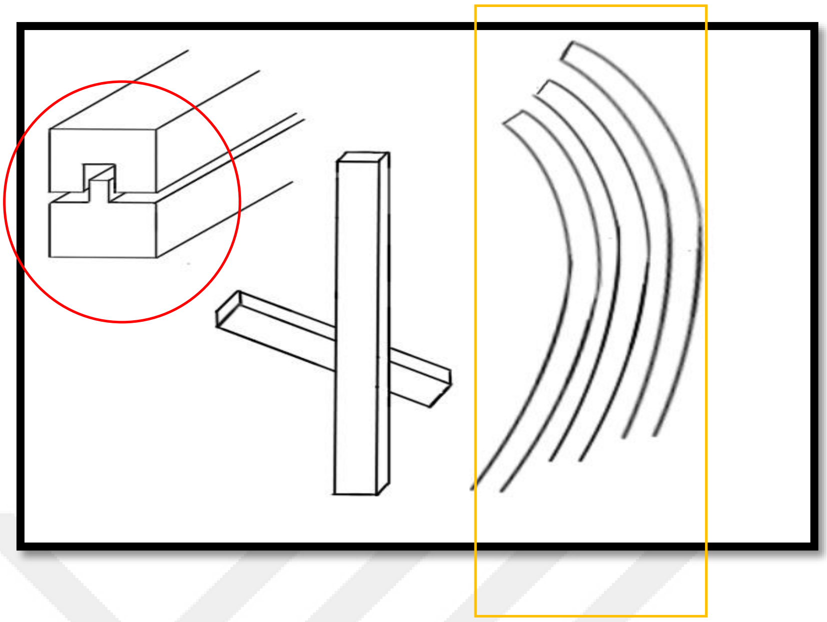
The wooden elements were crossing and meeting at one column as a common element. Indeed, this thesis is focused on the organic shapes, thus the design progress and evaluation has been based on that criterion. In order to produce organic shapes, the utilization of parametric rules and changing them in different segments end up in new sizes, shapes, pattern cells hence the design alternatives (Figure 4.7). The new alternatives of shapes were created by use of Rhinoceros and Grasshopper.

Figure 4.6: Sketch of wooden beams and columns from Iplidzik Mosque



Wooden beams and columns at Iplidzik mosque as an inspiration for the new roof proposal

Figure 4.7: Sketch of wooden joints and new shape elements

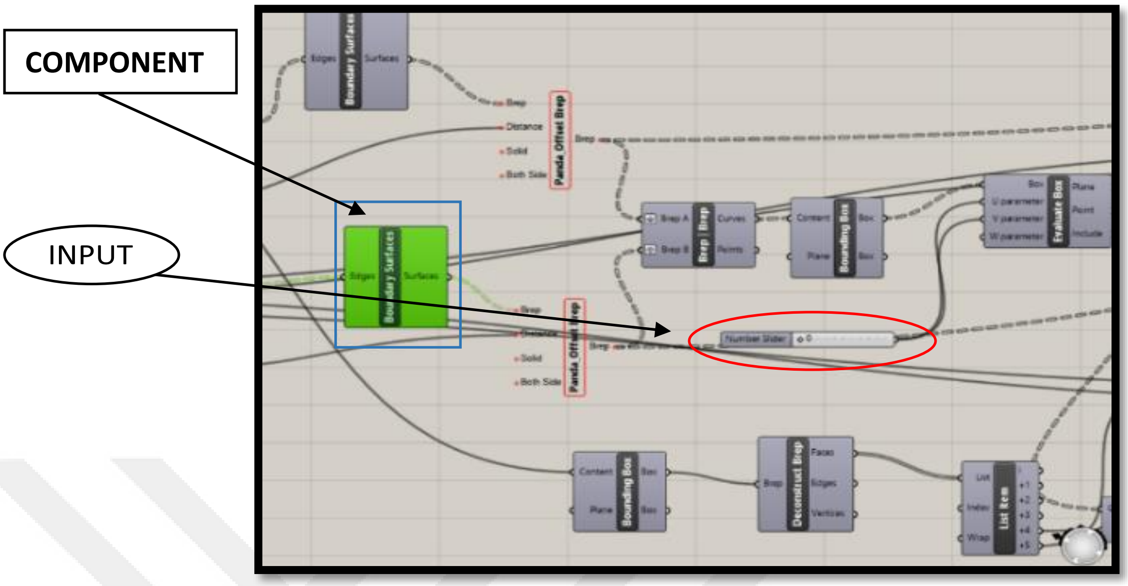


4.3 DEFINITION

A parametric model owns inputs which are used by different operating software types which create outputs for geometry. Specifying the coordinates for different axes, and using the commands for modelling are leading to generating geometry. All different components can be expressed through their interrelationship in the sense of size or distance, instead of manually working for whole geometry segments.

A model can be defined by using components, where each component has its own programming commands which together execute mathematical operations or geometry (Figure 4.8). The left side of the figure is showing the components which create series of values from data, start number, and number of values. Placing and connecting of the components is leading to model formation and then geometry is generated. From three coordinate values, a point in the 3D space of Rhinoceros has been created. From these points beams were created from several other components that resulted in the geometrical form showed at right side of the figure. In this model, Grasshopper has been used as a tool which has a good interrelation of inputs and outputs. Indeed, building geometry is strongly developed in this coding system since there is no other individual command system.

Figure 4.8: Example of Grasshopper parametric model and the geometrical representation of an algorithm

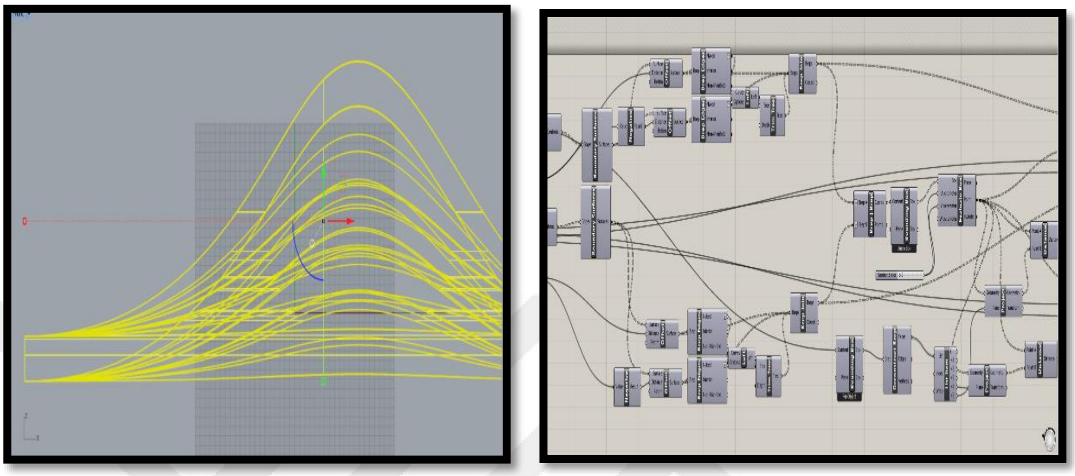


Parametric model contain inputs that work by application of diverse mathematical operations, hence output has been created in the form of generated geometry. However, at this case a model is defined by using of components. Drawing of the model has explicit dimensions, but the design decision process means that algorithms are left implicit. The main purpose of parametric modeling is to connect all components to each other where model is formed and geometry is generated.

4.4 MODELING

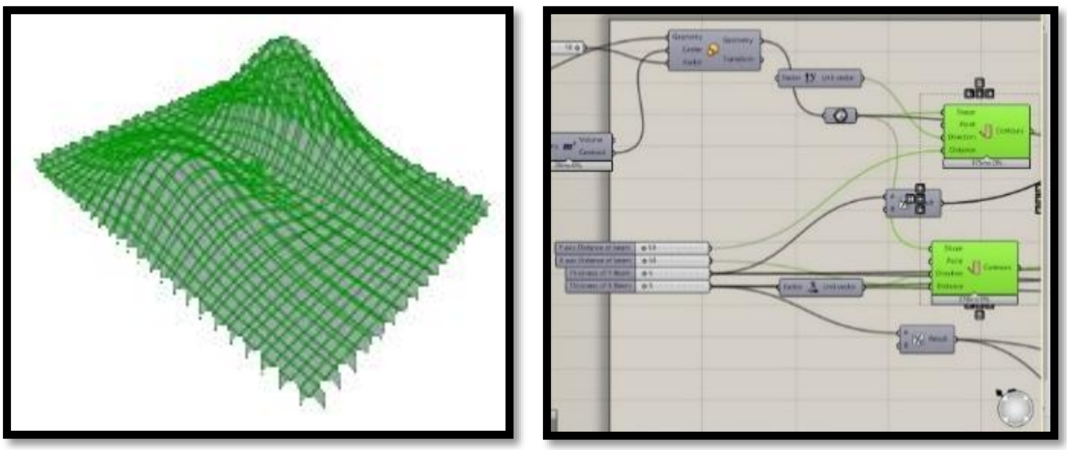
The parametric platform used in this thesis are Grasshopper and Rhinoceros. Indeed, they offer a fast, user-friendly and geometrically representative way of programming for architects and designers. In addition to these two types of software, plugins with diverse functions and purposes have been created as well. Parametric design has a very high potential at early stages of designing, due to independence for many design parameters to affect the modelling. The panda plugin has been applied through this research to model the roof with a rapid simulation of different parameters. However, Panda offers many tools for Grasshopper, hence for this roof “Offset for Solid structures” has been applied. Geometry is represented over the coding system which is quite powerful and its use is very functional since it is not a fixed code, but can be changed by other designers (Figure 4.9). Grasshopper is a tightly integrated program with Rhino’s 3D modeling tools.

Figure 4.9: a) Geometrical representatıon in Rhinoceros b) Parametric model in Grasshopper software



The initial proposal of the roof model and Grasshopper code are represented in Figure 4.10. In the model, simple rectangular shapes are created. Model proposal had a structure of beams in two directions, where two axes are creating a roof system. A code has been created by using Grasshopper, hence at every instance of new commands or parameters, the model changes its shape to Rhinoceros.

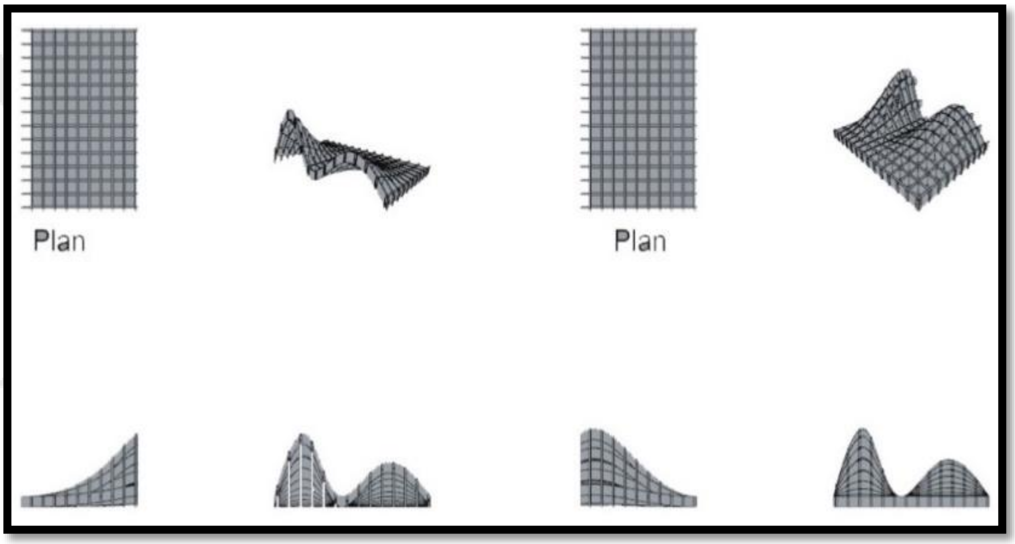
Figure 4.10: Contouring the roof in both directions



The design of the code has been started by the Brep function which is used for ensuring that the whole model is functional. It is Boundary Representation; the surface with trim curve information.

One of the starting points are at the two integer accuracies X and Y (Figure 4.11). Indeed, the proposal required further evaluation of much complex structure and geometry. In order to find a logic system and form the roof structure, Grasshopper code has offered different solutions.

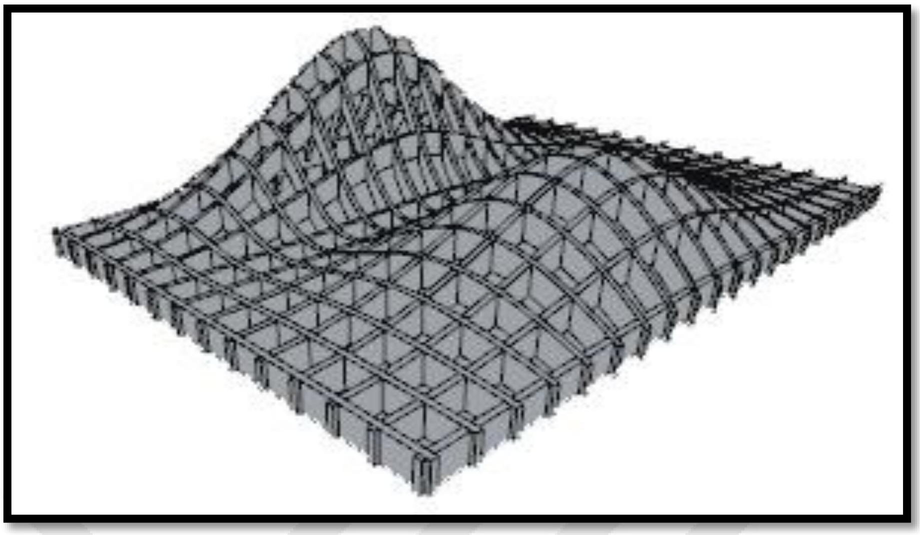
Figure 4.11: Roof sections



The current design progress had a structural form that required to be tested more and evaluated in order to get a proper parametric design shape. However, the initial model used the beam and the column elements from the Iplidzik Sinan Mosque for providing the new roof proposal.

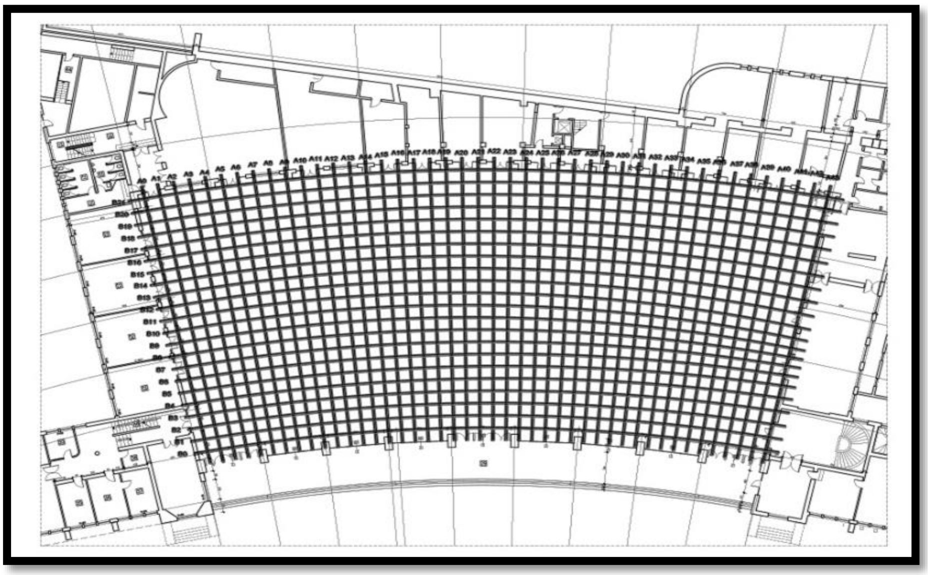
The intention was to develop a roof system, which would consist of the elements of the Iplidzik Sinan Mosque, resulting in parametric logic and form. Figure 4.12 renders the roof concept of two-way beams, exposing the structural roof system.

Figure 4.12: Initially Proposed roof model



The represented geometry of the initial proposal of the roof failed to fulfill the criteria of parametric design. Indeed, Grashopper had a complex code which required to be further developed for the progressing of new geometries. Figure 4.13 shows the further progress of the roof plan, modelled after the code comand edition.

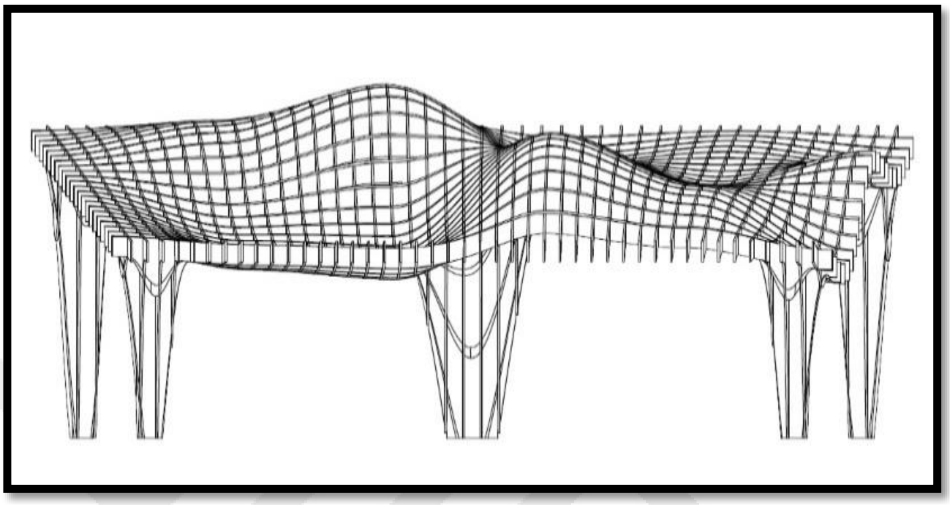
Figure 4.13: Train station existing plan drawing & model proposal plan



Further model development has been explored by following the existing elements of Iplidzik Sinan Mosque, translated into the Grasshopper modeling and parametric design.

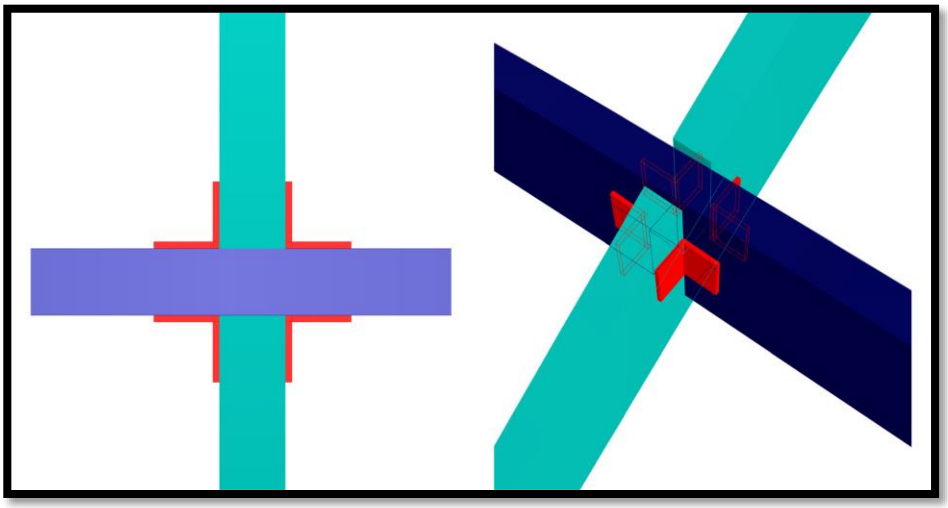
The logic of using the structural symmetrical beams and columns of the Iplidzik Sinan Mosque, which were applied in Grasshopper, evaluated the model into a new shape (Figure 4.14).

Figure 4.14: Front Side of the Proposed Roof Structure



A new asymmetrical form has been created; five columns have been modeled which serve as a construction of roof elements. The parametric roof was placed and connected with joints (Figure 4.15). Glulam material has been used for this roof structure, due to long its span, simple installation and its light weight.

Figure 4.15: Joint elements used for the roof model



Further progress of the model and the Grasshopper code is shown in Figure 4.16 and Figure 4.17.

Figure 4.16: Right Side

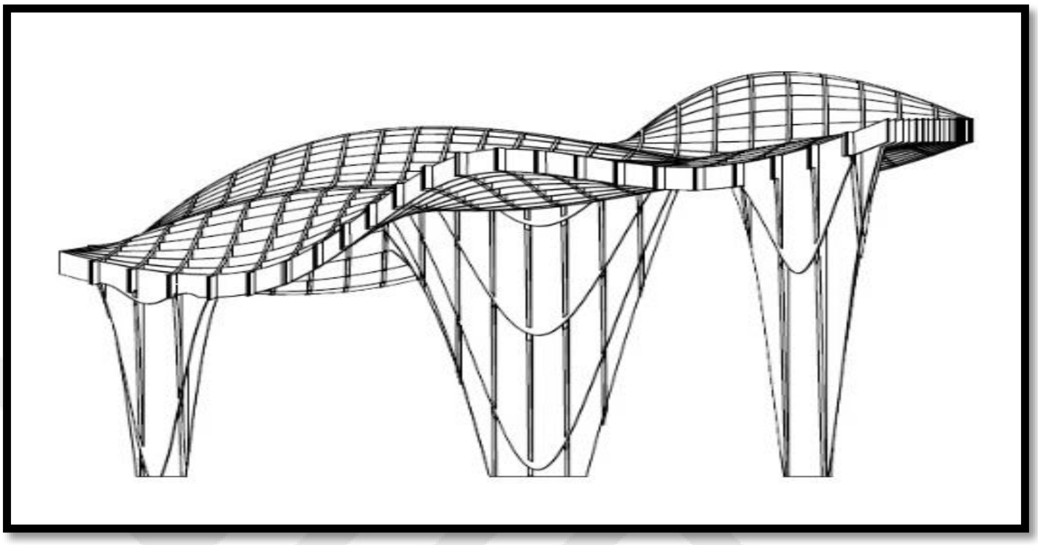
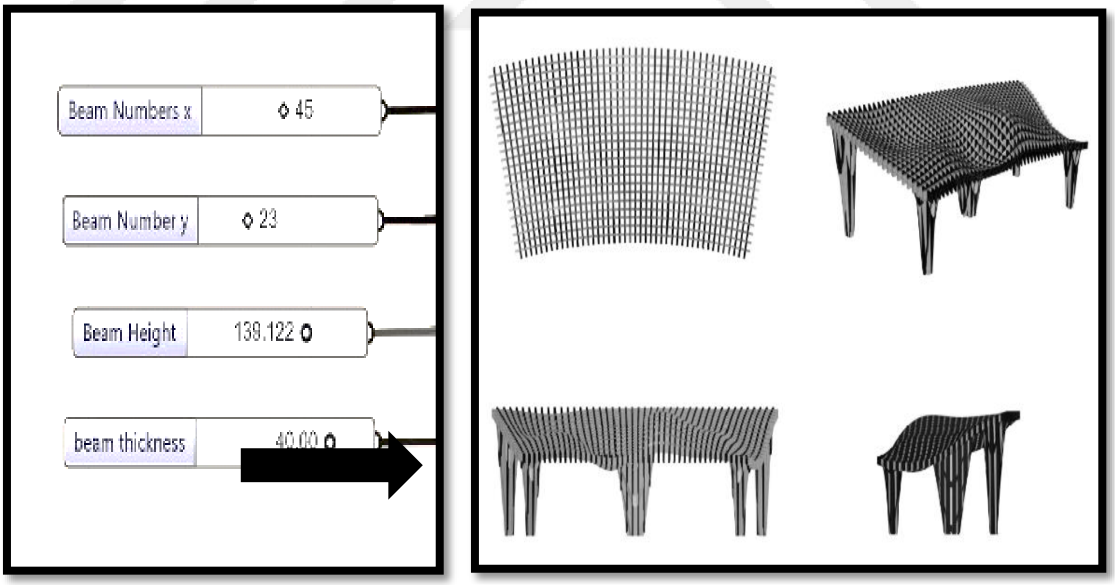


Figure 4.17: Beam through different thicknesses and numbering



In order to understand better the overall progress, sections were done at Rhinoceros. Figure 4.18 and Figure 4.19. Present longitudinal and transverse section of new roof proposal.

Figure 4.18: Section A-A

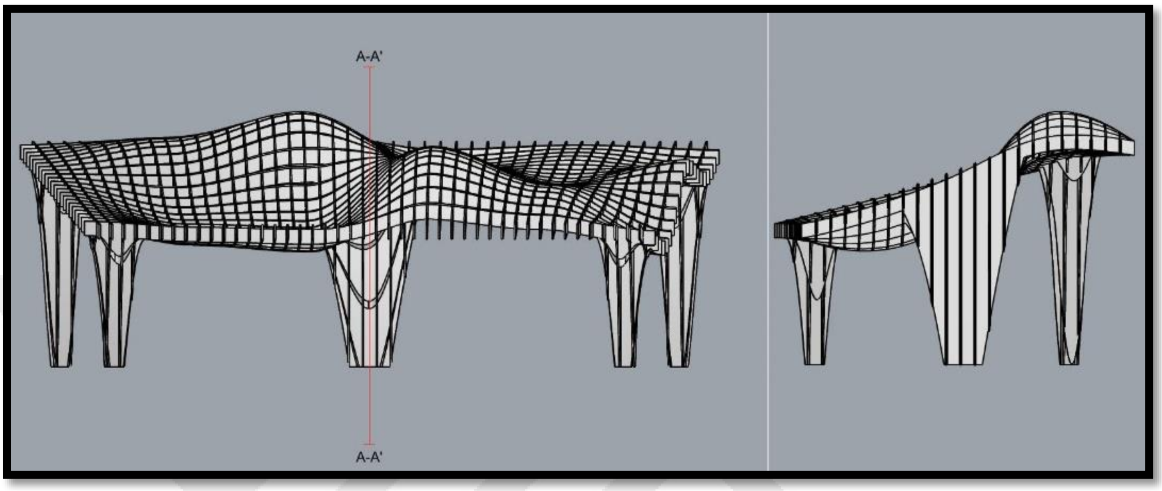


Figure 4.19: Section B-B

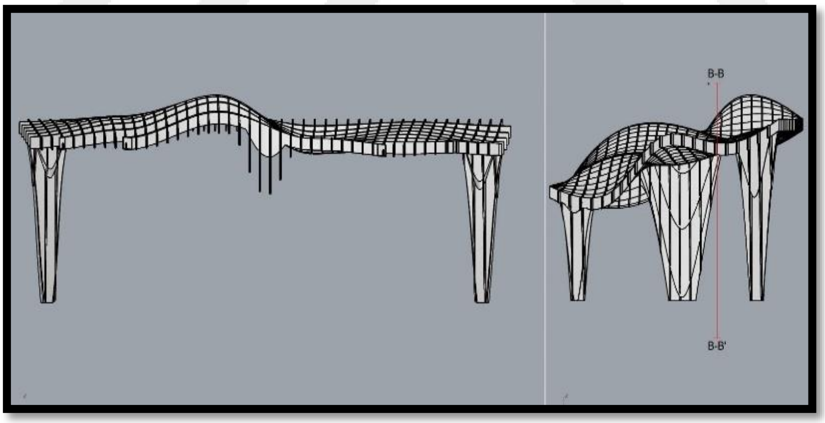
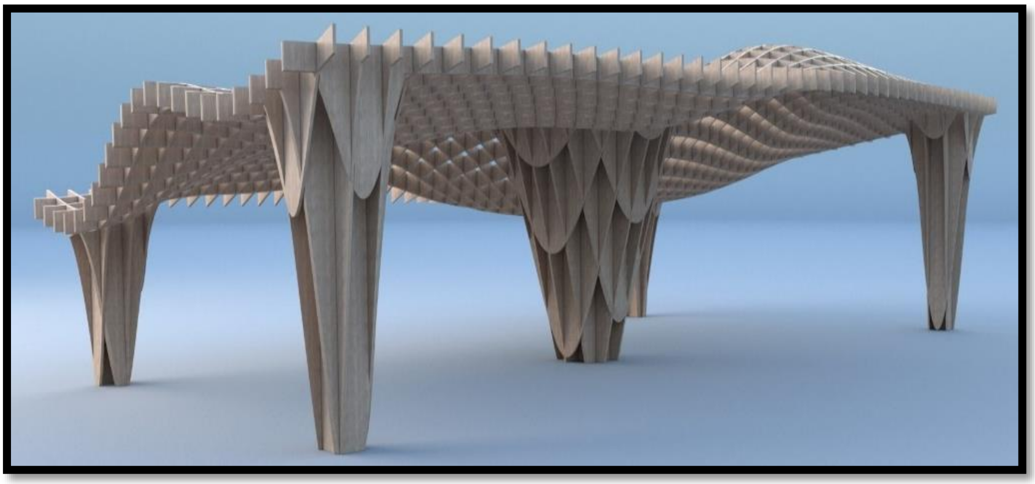
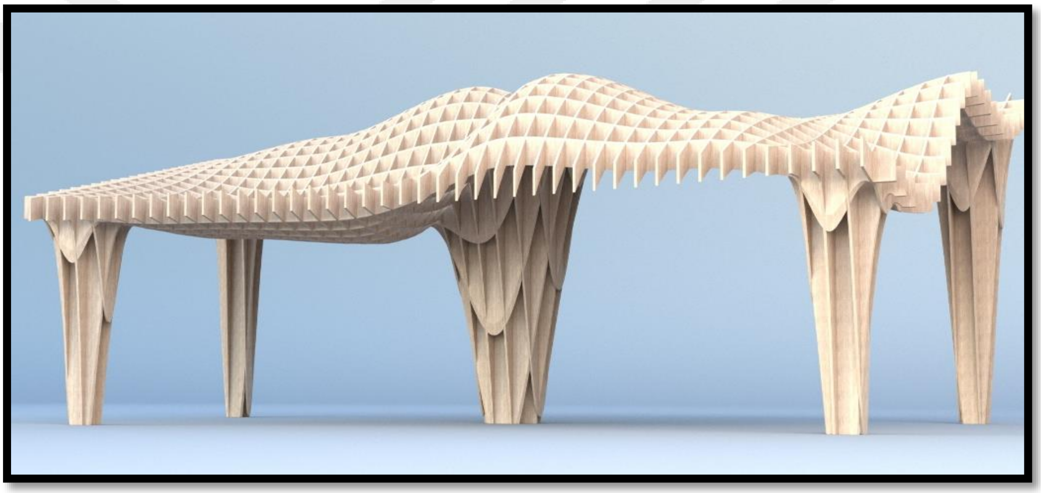


Figure 4.20 show the final roof structure of the model in which wood is used as the base material. The overall modelling of the roof is completed with renderings made in Rhinoceros and Grasshopper.

Figure 4.20: Final roof model





4.5 ANALYSIS

The recent situation and needs of the Train Station in Sarajevo dispose with some critical zones of the interior and exterior part. To have a better understanding of the overall project, study trip was done: a visit to both the Train Station in Sarajevo and the Iplidzik Sinan Mosque. The current architectural situation at Train Station is still in very bad condition; the interior requires an urgent reconstruction. Unfortunately, the video and the photo media was not allowed due to the laws of B&H. However, request to the staff of the station, enabled a small amount of photographs to be taken. Indeed, the Iplidzik Sinan Mosque from the 16th century (Figure 4.21), is in a process of reconstruction by which the old construction techniques and rules will be developed with new building technologies.

Figure 4.21: Detail from Iplidzik Sinan Mosque, 16th Century, Sarajevo

Source: https://goo.gl/Hy3f7B

Initial progress of sorting of the elements from the Iplidzik Sinan Mosque, resulted in some limitations in terms of the structural system and the timber structures. When it comes to the structural system, the mosque has been constructed in the early 16th century when geometry and structure of carrying loads was assumed in a logic way of constructers. Timber structure, especially represented in the exterior was used as the main segment for the development of the new roof model. In order to be able to understand the structure, symmetrical representation of beams and columns has been studied.

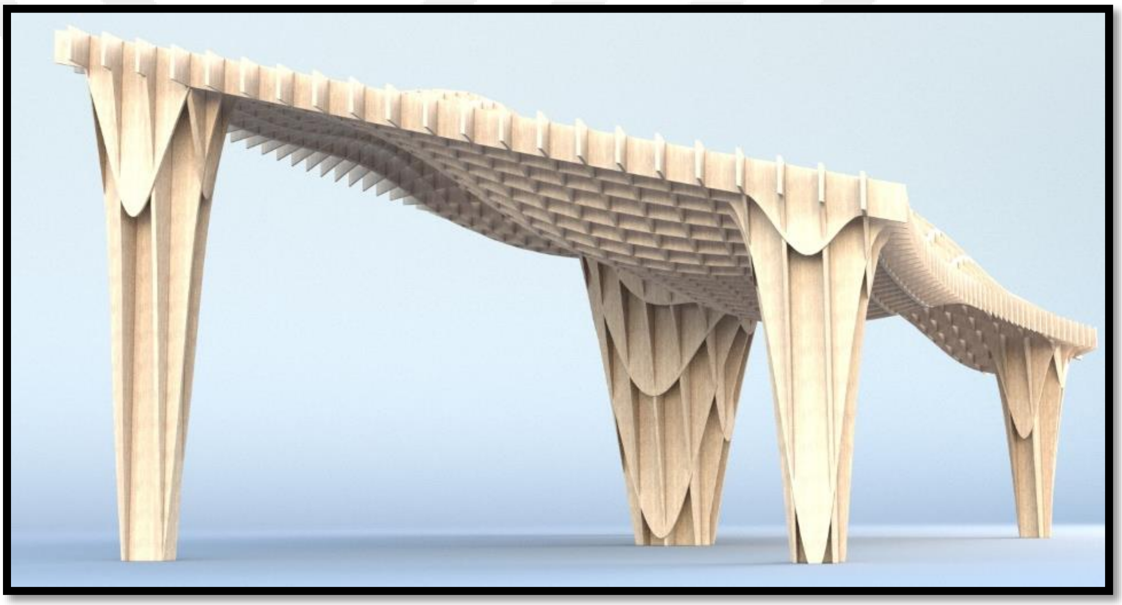
The initial development started by drawing and sketching the elements, to create the idea of the structure, which served as a basis for the design of the new roof design. Indeed, very symmetrical wooden beams and columns were not leading to organic and parametric forms. By application of these forms into Grasshopper and by applying commands to create a code, new shapes of organic forms were formed and modeled. Obviously, due to understanding of the general structural system, a new stage for parametric design has been applied. The parametric model and constructional system have been developed according to diverse and relevant parameters.

The new form has been created, where symmetry has been accomplished in order to provide asymmetrical forms. The process of finding a proper structural system for the roof required the understanding of the limits of design and modelling. Use of a long span, creating light roof structure and production methods for parametric shape required material to be able to solve these limitations.

Recently, B&H has been producing glued laminated material. An advantage of this material is that it is structurally strong but in visual sense can be expressed as a very complex and remarkable form. Glued laminated timber or glulam, has been used for production of this roof model. Due to the long span of the Train Station, glulam is a great material because it is manufactured to handle stress and longer spans of up to fifty meters.

Figure 4.22 shows the new roof structure where columns and beams preserve the expression of the old Iplidzik Sinan Mosque.

Figure 4.22: New roof structure by use of long span glulam panels



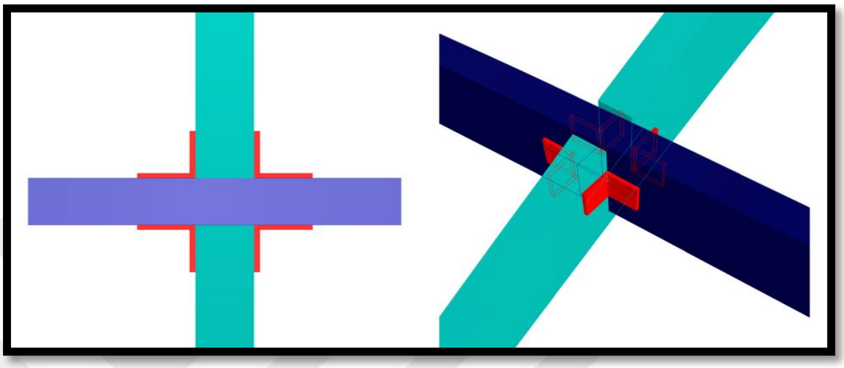
5. CONCLUSION

By applying parametric methods and tools, this thesis proposes a new roof design for the old train station in Sarajevo, inspired by local materials and their techniques. Main motivation is to exemplify a bond between vernacular wood architecture in B&H and parametric design. Despite the apparent diversity that has been brought by contemporary architecture, there is still a potential for designing with vernacular techniques.. Contemporary architecture in B&H may employ tectonics which inherit constructive and aesthetic rules from vernacular structures.

5.1 OUTCOMES OF THE MODEL

In order to develop a parametric model for this thesis it required programing skills, in this case Grasshopper and Rhinoceros were used with an application of plug in Panda. A set of mathematical operations were applied in diverse commands where a code was created. Coding system was represented through geometry which is quite powerful and the use of the same one later is very functional since it is not a fixed code, hence other designers can change it. The model was configured with compositional rules drawn from the vernacular wood architecture of B&H. The aim of this thesis was to use one of the elements of the Iplidzik Sinan Mosque in Sarajevo for inspiration of modeling of the new roof of the Train Station in Sarajevo. Aim of the thesis was also to look into the feasibility and limits of timber use and application. The roof model of the Train Station in Sarajevo, have two direction beams and five columns which are supporting the structure. As B&H is rich in forests, construction by application of glulam material was a logical selection. The other structural products do not offer enough design versatility to designers and architects as glulam. Advantages of this type of construction are its size, wide range of shapes and a long span. Aesthetics aside, this roof model has a strength and durability of glulam beams and columns, which is ‘homogenous’ because all of the laminations are of an identical strength class of wood. Assumed deviations in geometry for the portal frame and arch of this roof model is asymmetrical. Indeed, a combined structure type is represented by use of diverse change of parameters in Grasshopper, where beams have different positions, heights and widths. Glulam timber is a very strong material so it requires proper connection detailing. The position of the connectors of the roof structure for the Train Station in Sarajevo is limited due to glulam use. Joints were applied to the elements that had less side tension on the members because glulam material should avoid highly stressed areas for connectors (Figure 5.1).

Figure 5.1: Joint elements used for the roof proposal

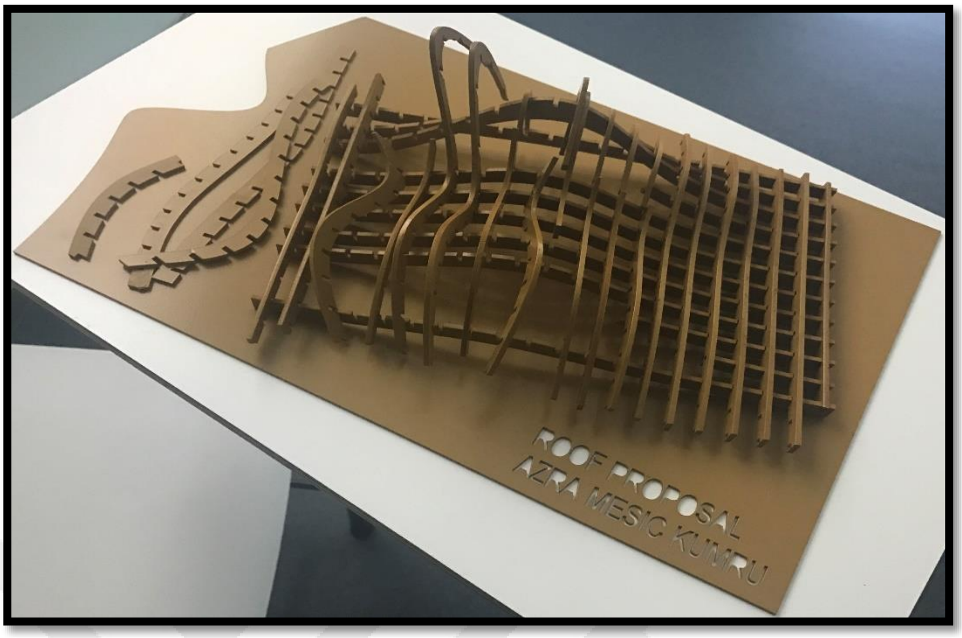


Digital prototyping and manufacturing such as CNC cutters and 3D printers offer various opportunities for digital design (Figure 5.2). Roof proposal was manufactured on the CNC cutter (Figure 5.3). Since there are limits related to cutting depending on the material and its thickness, the wood material of 2 mm thickness was chosen.

Figure 5.2: Laser cutter, 3D printer and CNC machine

Source: http://tl.tc/gG9i5 http://trlink.org/nn2ZrG http://link.tl/17ZfA

Figure 5.3: Mock up model of the roof proposal

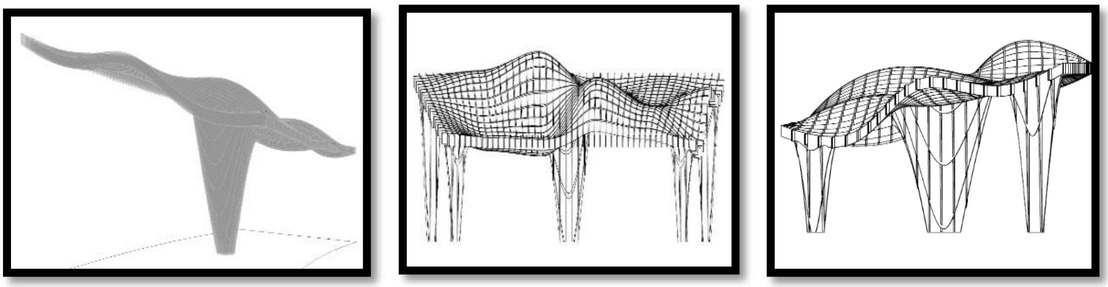


5.2 DISCUSSION & FURTHER SUGGESTIONS

In this current design progress, an early phase of the parametric model is introduced where the code and the model are cooperating to create new forms. Some of the questions that might be investigated in future research are: How far can geometry progress by the use of this code? What would be the codes that would automatically solve the joint parts for the output structure? However, what is clear is that each new command and parameter in Grasshopper will generate a new form, and once the code is applied, every emerging form will have a parametrical relation to the initial geometry. Parametric design with Grasshopper requires needs some coding skills as well as a detailed knowledge of geometry and analysis.

Figure 5.4 shows different forms and elements developed from one code system by the use of Grasshopper in terms of parametric design.

Figure 5.4: Different forms and elements of parametric design



Grasshopper is offering a parametric flow to evaluate unlimited variations and product of the system that has been done for one code. The progress of the coding system is relatively slow, hence once it is done, and the code is flexible to change geometry rapidly and easily. Indeed, projects are getting more complex hence the needs of parameters are growing up, therefore the knowledge of geometry and analysis is required. Further work of this thesis may cover a wider number of topics such as:

i. Creating an open-source library for this code system.
ii. Develop much complex structure in Grasshopper by use of the existing code.
iii. Further evaluation of the output geometry such as structural optimization or Daylight optimization etc.
iv. To finalize model at 1:1 scale.

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