ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

AN EXPERIMENTAL STUDY ON LOAD BEARING TIMBER GLASS COMPOSITE SHEAR WALLS UNDER MONOTONIC AND CYCLIC LOADINGS

M.Sc. THESIS

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Department of Architecture

Environmental Control and Construction Technologies Programme

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MONOTONİK VE ÇEVRİMSEL YÜKLER ETKİSİNDE AHŞAP CAM KOMPOZİT TAŞIYICI PERDE DUVAR ELEMANLARI ÜZERİNE DENEYSEL BİR ÇALIŞMA

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To my mother,

FOREWORD

I hereby declare that all information in this thesis has been obtained and presented in accordance with academic rules and ethical conduct. Firstly, I would particularly like to thank my family and my fiance who have always encouraged me to go further. I would like to sincerely thank my thesis advisor Ass. Prof. Dr. Halet Almıla Büyüktaşkın for her inexhaustible patience and guidance. I am grateful to Dr. Gülseren Erol for her great support and advice. I would also like to thank Trakya Glass Industry fabric (Trakya Cam Sanayii A.S.) and Turkish Timber Association for procurement of materials and The Scientific and the Research Council of Turkey (Tubitak) for provide the fund to project and to thank workers of ITU Structural and Earthquake Engineering Laboratory and Metal Yapı A.S. for their valuable helps during experiments.

May 2015 Güzide ASLANKAYA

TABLE OF CONTENTS

Page

FOREWORD ..... **ix**
TABLE OF CONTENTS ..... **xi**
ABBREVIATIONS ..... **xv**
LIST OF FIGURES ..... **xix**
SUMMARY ..... **xxiii**
ÖZET ..... **xxvii**
1. INTRODUCTION **1**
1.1 Topic introduction 1
1.2 Aim and limitations 2
1.3 Outline of the thesis 3
2. SURVEY OF LITERATURE **5**
2.1 Timber as a Material 5
2.1.1 Structure and General Properties of Timber 5
2.1.1.1 Structure of Timber 5
2.1.1.2 Defects in Internal Structure of Tree 6
2.1.2 Types of Timber 7
2.1.3 Physical Characteristic of Timber 9
2.1.3.1 Colour and Odour 9
2.1.3.2 Thermal Conductivity 9
2.1.3.3 Sound Transmission 10
2.1.3.4 Moisture Content 10
2.1.3.5 Density and Specific Gravity 11
2.1.3.6 Timber Defects 11
2.1.3.7 Dimensional Stability 11
2.1.4 Chemical Characteristic of Timber 12
2.1.5 Mechanical Characteristic of Timber 13
2.1.5.1 Strength in Tension 14
2.1.5.2 Strength in Compression 14
2.1.5.3 Modulus of Elasticity 14
2.1.5.4 Modulus of Rupture 14
2.1.5.5 Shear Strength, Shear Modulus 15
2.1.6 Advantages and Disadvantages of Timber as a Building Material 15
2.1.7 Timber Preservation 17
2.2 Building systems in timber structures 18
2.2.1 Traditional Timber Structural Systems in Turkey 18
2.2.1.1 Himis 18
2.2.1.2 Bagdadi 19
2.2.2 Timber Log Structures 19
2.2.3 Timber Frame Structures 20
2.2.3.1 Platform Frame 20

2.2.3.2 Balloon Frame 21
2.2.4 Timber Panel System 22
2.3 Timber Composites 23
2.3.1 Glued-laminated Timber 24
2.3.2 Structural Composite Lumber 25
2.3.3 Particleboard 25
2.3.4 Flakeboard 25
2.3.5 Fiberboard 26
2.3.6 Plywood 26
2.3.6.1 Standarts of Plywood 28
2.4 Examples of Timber Building Structures in Turkey 29
2.5 Glass as a Material 33
2.5.1 Production of Glass 33
2.5.2 Structure and General Properties of Glass 34
2.5.2.1 Structure of Glass 34
2.5.2.2 Properties of Glass 34
2.5.2.3 Advantages and Disadvantages of Structural Glass 37
2.5.3 Types of Glass 37
2.5.3.1 Float Glass 37
2.5.3.2 Heat-treated Glass 37
2.5.3.2.1 Tempered Glass 38
2.5.3.2.2 Heat-strengthened Glass 39
2.5.3.3 Assemblies of Glass 39
2.5.3.3.1 Laminated Glass 39
2.5.3.3.2 Insulating Glass 40
2.5.3.4 Coatings 41
2.5.4 Standarts of Glass 41
2.6 Structural Glass Elements 42
2.6.1 Glass Beams 42
2.6.2 Glass Columns 44
2.6.3 Glass Shear Walls 45
2.7 Examples of Glass Structures in Turkey 46
2.8 Adhesives 49
2.8.1 General and mechanical properties of adhesives 49
2.8.2 Adhesives for timber glass composites 52
2.8.3 Silicone for timber glass composites 54
2.8.4 Standarts of Adhesives 55
2.9 Timber Glass Composites 56
2.10 Examples of Timber Glass Composites in Turkey 58
3. EXPERIMENTAL TESTS 63
3.1 Previous Experiments Under Seismic Loads 63
3.2 Monotonic and Cyclic Tests of Large Size Specimens 78
3.2.1 Experimental Materials and Methods 79
3.2.1.1 Materials and their properties 79
3.2.1.1.1 Plywood 79
3.2.1.1.2 Glass 79
3.2.1.1.3 Adhesives 80
3.2.1.2 Test Methods 80
3.2.1.2.1 Test Configuration 80
3.2.1.2.2 Loading Procedure 84

3.2.2 Experimental Tests 89
3.2.3 Test Results 94
3.2.4 Comparison of Test Results with Previous Test Results 96
3.3 Long Term Loading Test of Medium Size Specimens 97
3.3.1 Experimental Material and Methods 97
3.3.1.1 Materials and their properties 97
3.3.1.2 Test Methods 98
3.3.2 Experimental Tests 102
3.3.3 Test Results 103
3.3.4 Comparison of Test Results with Previous Test Results 106
4. PILOT PROJECTS 109
4.1 Bus Stop 109
4.2 Resting Place 113
4.3 Bagel Kiosk 116
4.4 Soldier Cabin 116
4.5 Result of Pilot Projects 117
5. MARKET SURVEY 119
5.1 Timber Market Survey 119
5.2 Glass Market Survey 126
5.3 Results of Market Survey 133
6. CONCLUSIONS 135
REFERENCES 139
CURRICULUM VITAE 147

ABBREVIATIONS

ACA : Ammoniacal Copper Arsenate
BS : British Standarts
cm : Centimeter
CLT : Cross Laminated Timber
CO2 : Carbon dioxide
DIN : Deutsches Institut für Normung
EU : European Union
GPa : Gigapascal
ITU : Istanbul Technical University
kg/m^3 : Kilogram per cubic metre
kN : Kilonewton
LBTGC : Load Bearing Timber Glass Composites
LFWC : Light framed timber construction
LSL : Laminated strand lumber
LVDTs : Linear Variable Differential Transformer
LVL : Laminated veneer lumber
MoE : Bending Modulus of Elasticity
MOR : Modulus of Rupture
MPa : Megapascal
mm : Millimetre
OSB : Oriented strandboard
PCP : Pentachlorophenol
PSL : Parallel strand lumber
PVB : Polyvinyl butyral
SSG : Structural sealant glazing
TSE : Turkish Standards Institution
TU : Technische Universität
USA : United States of America
UV : Ultraviolet
WB : Waferboard

LIST OF TABLES

Page

Table 2.1 : Approximate change (%) of clear timber properties for a one-percentage change of moisture content 15
Table 2.2 : Properties of the glass 35
Table 2.3 : Classification of polymer adhesives 49
Table 2.4 : General comparison of different adhesive systems 51
Table 2.5 : Suitable tests for obtaining mechanical values 56
Table 3.1 : Loading steps of monotonic tests. 85
Table 3.2 : Loading steps of cyclic tests. 86
Table 3.3 : Test results of SPM-2 and SPC-1. 96
Table 3.4 : Total vertical displacement values of medium-size specimen at the end of first 174 days. 105

LIST OF FIGURES

Page

Figure 2.1 : Cross-section of tree trunk 6
Figure 2.2 : Defects of timber (www.woodmagazine.com)..... 7
Figure 2.3 : (A) The general form of a generic softwood tree 9
(B) The general form of a generic hardwood tree,
(C) Transverse section of typical softwood,
(D) Transverse section of a typical hardwood,. 9
Figure 2.4 : Characteristic shrinkage and distortion of timbers as affected by direction of growth rings 12
Figure 2.5 : Three principal axes of timber with respect to grain direction and growth rings 13
Figure 2.6 : Himis system 18
Figure 2.7 : Bagdadi system 19
Figure 2.8 : Sketch of the Log Timber Grove Meetinghouse drawn by Dorothy B. 20
Figure 2.9 : Platform Frame 21
Figure 2.10 : Balloon Frame 21
Figure 2.11 : Timber Panel System..... 21
Figure 2.12 : Types and usage rate of load bearing system in timber building, Istanbul..... 23
Figure 2.13 : Examples of various composite products 24
Figure 2.14 : The structure of a three-ply plywood 27
Figure 2.15 : Rum Orphanage in Buyukada, Istanbul..... 30
Figure 2.16 : Exterior and interior view of The Architect's Office, Urla. 30
Figure 2.17 : System details of The Architect's Office, Urla 31
Figure 2.18: Ilyas Bey Islamic Social Complex, Aydın 31
Figure 2.19 : Ipera 25 apartment building..... 32
Figure 2.20 : Office Building In Istanbul by Tago Architects, ... 32
Figure 2.21 : Production of glass. 33
Figure 2.22 : Strees-strain of the glass. 36
Figure 2.23 : The residual stress field in tempered glass (Bength, 2005) and the figure of tempered glass (Savic, 2013). 38
Figure 2.24 : Comparison of the fracture pattern: annealed glass (left), heat-strengthened glass (middle), fully tempered glass (right)..... 39
Figure 2.25 : Post breakage behaviour of laminated glass made of different glass types. 40
Figure 2.26 : Components of the insulated glass, ... 41
Figure 2.27 : Buildings with glass beams 43
Figure 2.28 : Timber glass beams in conference room 44
Figure 2.29 : Glass column in Administration building in Saint-German-en-Laye, Paris, 1994..... 45

Figure 2.30 : Specimen of timber glass shear wall. 46
Figure 2.31 : Glass Kiosk (Camli Kösk) in Dolmabahce Palace, 1856 46
Figure 2.32 : Vakko Headquarters in İstanbul, Turkey 47
Figure 2.33 : The X-Shaped Glass Panels. 47
Figure 2.34 : Sapphire Tower. 48
Figure 2.35 : Tekfen Oz Office Building and its double-glazed façade 48
Figure 2.36 : Connection between stiffness and elasticity for common adhesive systems 51
Figure 2.37 : Roof Construction of Ertaş and Bakırcılar bazaars, Bursa 58
Figure 2.38 : Çanakkale Seramik Headquarters. 59
Figure 2.39 : Laminated timber beams of building. 59
Figure 2.40 : A swimming pool, Vedat Tokyay - Oran Architecture 59
Figure 2.41 : Summer house, Dikili, 2002 60
Figure 2.42 : Dardanel Administration Building 60
Figure 2.43 : Second set of glass doors and glass-roofed of building 61
Figure 2.44 : Floor-to-ceiling windows of meeting room, staircase and elevator 61
Figure 3.1 : Shematic diagram of specimens 64
Figure 3.2 : Static-cyclic test setup 65
Figure 3.3 : Reliability curves for the shear wall with sustainable mass obtained from Tokyo earthquake records with: 10% and 2% probability of exceedance in50 years 65
Figure 3.4 : Sketch of the dynamic racking test setup. 66
Figure 3.5 : Sketch of the test specimens. 68
Figure 3.6 : Sketch for general arrangement of test setup. 68
Figure 3.7 : The plan of curtain wall model 69
Figure 3.8 : Test Configuration of 3P of CLT wall panel 70
Figure 3.9 : The test samples were subjected to the horizontal point load at the top edge. 71
Figure 3.10 : Cohesive failure in the silicone 71
Figure 3.11 : Force-deformation diagram for the first specimen 72
Figure 3.12 : The simple transverse reinforcement for the second specimen 72
Figure 3.13 : Force-deformation diagram for the second specimen 72
Figure 3.14 : Graphical representation and photograph of the steel test frame 73
Figure 3.15 : Force-deformation diagram for the third specimen 73
Figure 3.16 : Test Configuration. 74
Figure 3.17 : Geometry of the specimens and cross-section from the testing group. 75
Figure 3.18 : Dimensions of timber-glass and light timber frame wall elements 77
Figure 3.19 : Configuration of single-storey and two-story test models 77
Figure 3.20 : Sheme of the force distrubation 78
Figure 3.21 : Ottocoll S660 and its compressed air gun 80
Figure 3.22 : Cross-section of large size timber-glass specimens, (Units are in mm.) 81
Figure 3.23 : Details of large size timber-glass specimens (Units are in mm.). 82
Figure 3.24 : Fabrication stage of large size timber-glass specimens. 82
Figure 3.25 : Steel loading frame (Units are in mm). 83
Figure 3.26 : Lateral loading of large size timber-glass specimens. 83
Figure 3.27 : Test set up large size timber-glass specimens. 84
Figure 3.28 : Monotonic loading protocol as given in BS EN 594:1996. 84
Figure 3.29 : Cyclic loading protocol as given in BS EN 12512:2001. 85
Figure 3.30 : Measuring devices schema of large size specimen tests. 87

Figure 3.31 : Transducers for measuring the displacement on specimen, (respectively from left to right 1,2 and 5, 6, 8, 11 and 12 are given)... 88
Figure 3.32 : Pi-gauges for measuring the displacement adhesive bond line (respectively 19, 21 and 23 are given). 88
Figure 3.33 : Straingauges for measuring the strain values and elongation timber and glass (respectively 26, 27 and 28, 29 and 33 are given)..... 89
Figure 3.34 : Connection of the switch box. 89
Figure 3.35 : Failure mode of SPM-1. 90
Figure 3.36 : Test configuration after the additional steel frame. 90
Figure 3.37 : Lateral load-top displacement diagram of SPM-2..... 91
Figure 3.38 : Failure mode of SPM-2. 92
Figure 3.39 : Lateral load top displacement diagram of SPC-1. 93
Figure 3.40 : Lateral load top displacement envelope of SPC-1. 94
Figure 3.41 : Failure mode of SPC-1. 94
Figure 3.42 : Lateral load- top displacement diagrams of SPM-2 and SPC-1. 95
Figure 3.43 : Cross-section of specimen with silicone and polyurethan adhesive .. 96
Figure 3.44 : Section properties of timber-glass specimens (Units are in mm). 98
Figure 3.45 : Dimensions of medium-size specimens (Units are in mm). 98
Figure 3.46 : Fabrication of medium-size timber glass specimens. 99
Figure 3.47 : Loading box details of medium size specimen test. 99
Figure 3.48 : Dimensions of the long term loading test set up, (Units are in mm). 100
Figure 3.49 : Layout plan of medium-size specimens placed at exterior conditions. (Units are of cm.) 101
Figure 3.50 : Medium size specimen timber-glass specimens at exterior conditions..... 101
Figure 3.51 : Mechanical displacement sensors (comparameters) and the temperature and humidity measuring device. 102
Figure 3.52 : Increased load on the medium size specimens for long term loading at exterior conditions. 103
Figure 3.53 : Digital displacement measuring device (left) and automatic moisture measuring device (right). 103
Figure 3.54 : Climatic variations diagram for the first 174 days. 104
Figure 3.55 : Climatic variations diagram for 12 weeks (90 days). 104
Figure 3.56 : Total displacements values of medium size specimen for the next 12 weeks (90 days). 104
Figure 4.1 : The design of the bus stop. 104
Figure 4.2 : The plan of the bus stop. 104
Figure 4.3 : One panel (left) and combination detail of panels (right). 104
Figure 4.4 : Drawing of front view (left) and side view (right). 104
Figure 4.5 : Front view (left) and side view (right). 104
Figure 4.6 : Weld bracket beam to beam and smaller side plate used for beam to column. 103
Figure 4.7 : Bearing plate (left) and simple steel dowel (right) for colomn to base. 103
Figure 4.8 : Hexagon place in ITU Faculty of Architecture campus. 113
Figure 4.9 : Perspective view (left) and top view (right). 114
Figure 4.10 : Side view (left) and inside view (right). 114
Figure 4.11 : Perspective view. 114
Figure 4.12 : Top view (left) and side view (right). 115

Figure 4.13 : Perspective view. 115
Figure 4.14 : Top view (left) and side view (right). 115
Figure 4.15 : Perspective view (left) and side view (right). 116
Figure 4.16 : Dolmabahce Palace gate (left) and perspective view (right). 116
Figure 5.1 : Graphical result of the first question of timber survey. 119
Figure 5.2 : Graphical result of the second question of timber survey. 120
Figure 5.3 : Graphical result of the third question of timber survey. 120
Figure 5.4 : Graphical result of the 4th question of timber survey. 121
Figure 5.5 : Graphical result of the 5th question of timber survey. 122
Figure 5.6 : Graphical result of the 6th question of timber survey. 122
Figure 5.7 : Graphical result of the 7th question of timber survey. 123
Figure 5.8 : Graphical result of the 8th question of timber survey. 123
Figure 5.9 : Graphical result of the 9th question of timber survey. 124
Figure 5.10 : Graphical result of the 10th question of timber survey. 125
Figure 5.11 : Graphical result of the 11th question of timber survey. 125
Figure 5.12 : Graphical result of the 12th question of timber survey. 126
Figure 5.13 : Graphical result of the first question of glass survey. 127
Figure 5.14 : Graphical result of the second question of glass survey. 127
Figure 5.15 : Graphical result of the third question of glass survey. 128
Figure 5.16 : Graphical result of the 4th question of glass survey. 128
Figure 5.17 : Graphical result of the 5th question of glass survey. 129
Figure 5.18 : Graphical result of the 6th question of glass survey. 130
Figure 5.19 : Graphical result of the 7th question of glass survey. 130
Figure 5.20 : Graphical result of the 8th question of glass survey. 131
Figure 5.21 : Graphical result of the 9th question of glass survey. 131
Figure 5.22 : Graphical result of the 10th question of glass survey. 132
Figure 5.23 : Graphical result of the 11th question of glass survey. 132
Figure 5.24 : Graphical result of the 12th question of glass survey. 133

AN EXPERIMENTAL STUDY ON LOAD BEARING TIMBER GLASS COMPOSITE SHEAR WALLS UNDER MONOTONIC AND CYCLIC LOADINGS

SUMMARY

By the broadest definition, a composite material is one in which two or more materials that are different are combined to form a single structure with an identifiable interface. The properties of that new structure are dependant upon the properties of the constituent materials. Within this study, timber and glass materials were attached together using a silicon adhesive, forming a composite.

Transparency in modern-day architecture has been playing a big role and influencing designs, and glass surfaces on buildings have been increasing every day as a result. Glass, although quite popular in usage in facades of buildings, is not a widely used element in load-bearing systems due to its brittle manner. Therefore, it is tried to combine with another material to minimise the probability of total glass failure.

Timber, when controlled tree production is provided, is a natural and renewable material. Being cheap to produce, consuming little energy and being renewable, combined with having supreme thermal insulation qualities; makes timber the best answer to the environmental and energy related problems today. Timber proves to be an essential element of construction with the evolution that has taken place in the last 20 years, and framed construction has been increasing in regions like Europe, North America and Japan.

Timber composite products have all the high mechanical and technological properties of massive timber. They are also high quality materials which don't have the negative properties of massive timber. Timber composite products provide rational usage of forest sources which are decreasing around the world as well as they give possibility to get products which satisfies the consumer and also meets the needs of them.

A European Project has been developed under the WoodWisdom-Net Research Program, knowing the potential of load bearing timber glass composite elements, for the purpose of meeting the future need. The countries in the international consortium are Austria, Germany, Sweden, Turkey, Slovenia, Chile and Brazil. Serving as an interdisciplinary bridge, this project is being supported by universities, research companies and industrial partners alike. Participants with considerable experience in the field have presented this forest based international research and development project to the WoodWisdom-Net Research Program under the ERA-NET WoodWisdom-Net 2 project. Each country is being sponsored by their national financial institutions. The Scientific and Technological Research Center of Turkey (TÜBİTAK) is the Turkish national funds organization. With the international project title "The Application of Load Bearing Timber-Glass Composite Structures for Building Construction" has the Turkish title of "Ahşap-Cam Kompozit Yapı

Elemanlarının Bina Taşıyıcı Sisteminde Uygulanması". The project aims to create practical constructional application methods by conducting long term atmosphere and strength tests on "timber-glass composite" beam, column, and curtain wall elements, to optimize the requested load-bearing system in the light of international data. It will therefore be possible for the product to be accepted in the construction sector and compete with other construction systems.

As part of this research project, it is aimed to;

- Optimize and develop composite timber-glass structural elements,
- Minimize the section of timber and glass,
- Research the strength of timber element,
- Develop the work environment of different industry corporations with international R&D project,
- Create eco-friendly, load-bearing system modules based on renewable resources,
- Reduce carbon dioxide emission by using low-energy materials (energy conservation),
- Develop the usage of renewable and replaceable structural materials,
- Lead to produce latest design codes and standards for composite systems based upon scientific facts.

In the working stages of the project, firstly dimensions of small size specimens were determined and the experiments were carried out in the laboratory (like adherence, shear and durability tests), medium size specimens were performed to long term loading at outside conditions, and large size specimens were tested under lateral loading (monotonic and cyclic loadings) and finally, pilot projects were designed. From 15 December 2011 to 15 December 2014, the project took 3 years to complete. This thesis, under the scope of the research project, consists of six main chapters. The introduction describes the purpose and the scope of the study. The second chapter contains a comprehensive literature scanning on timber, glass and adhesives which are the main subject of research has been carried out and it has been tried to collect as much data as possible related to the subject matters. In the third section, the long-term behavior of load bearing timber-glass composite elements and were investigated through experimentation under environmental conditions and also under lateral loading like earthquake. In the fourth chapter, based on data from the experiments, pilot project suggestions were designed and load-bearing timber-glass composite elements were presented as an appealing alternative structural systems in architecture as well. The fifth chapter contains the results of market surveys with glass and timber industries for the introduction and incorporation of the new timber-glass composite structural elements into the market. The sixth chapter includes evaluations and necessary recommendations based on the results and findings of the study.

One of the expected results is that timber, which is favored for ecological structures, will be used widely in different areas of usage, and glass will be encouraged to be used apart from the use with concrete and steel. The most important one of possible results is to create a high-competitive, multivalent structural system.

The fact that timber and glass composite elements will not need a heavy industry to be produced is also an important quality. Quite the contrary, these products can be manufactured quickly with low energy consumption of the production techniques. The market research results support the idea that timber-glass composites will find its place in the market. This new composite structural system will be used in several areas, such as winter houses, facade elements, prefabricated houses, greenhouses, office buildings, schools and kindergartens, elevator shafts, small objects, applications of transparent interior wall partition.

MONOTONİK VE ÇEVRİMSEL YÜKLER ALTINDAKİ AHŞAP CAM KOMPOZİT PERDE DUVARLAR ÜZERİNE DENEYSEL BİR ÇALIŞMA

ÖZET

Geniş anlamda kompozit malzeme, tanımlanabilir bir arayüze sahip tek bir yapı elde etmek amacıyla, iki ya da daha fazla sayıdaki farklı malzemenin bir araya getirilmesiyle oluşturulur. Bu yeni ürünün özellikleri, ürünü meydana getiren malzemelerin özelliklerine bağlıdır. Bu çalışma kapsamında, ahşap ve cam malzemeler silikon ile yapıştırılarak kompozit bir hale getirilmiştir.

Saydamlık günümüz mimarisinde önemli rol oynamakta ve tasarımlara yön vermektedir. Buna bağlı olarak binada kullanılan cam yüzeyler her geçen gün artmaktadır. Cam, yapılarda cephe elemanı olarak sıkça kullanılmasına rağmen aşırı kırılgan bir yapıya sahip olmasından kaynaklı taşıyıcı sistemde kullanımı yaygın değildir. Bu güçlüklükleri aşması açısından başka bir malzeme ile bir araya getirilmesi denenmektedir.

Ahşap, kontrollü ağaç üretimi sağlandığı takdirde doğal ve yenilenebilir bir malzemedir. Üretimi ve işlenmesi için az enerji istemesi, dönüşebilir olması ve üstün ısı yalıtım özellikleri ile birleştirilince onu çağımızın çevre ve enerji sorunlarına en iyi cevap veren malzemesi yapmaktadır. Ekolojik binalar için ahşabın önemli bir yapı malzemesi olduğunu son 20 yılda geçirmiş olduğu evrim ile kanıtlamakta, ahşap taşıyıcı yapıların sayısı Avrupa, Kuzey Amerika ve Japonya gibi bölgelerde hızla artmaktadır.

Ahşap kompozit malzeme de masif ahşap malzemede olduğu gibi yüksek değerde mekanik ve teknolojik özelliklere sahip olmakla birlikte, masif ahşap malzemenin sakıncalarını taşımayan, üstün nitelikli bir malzeme olmaktadır. Ahşap kompozit malzeme, dünyada azalmakta olan orman kaynaklarının ahşap endüstrisinde daha akılcı bir şekilde kullanılmasını sağlamanın yanı sıra, tüketiciyi memnun edecek ve ihtiyaçlarını karşılayacak nitelikte ürünler elde edilmesine imkan vermektedir.

Ahşap cam kompozit yapı elemanlarının potansiyelinin bilincinde, gelecek beklentileri karşılamak amacıyla, Woodwisdom-Net Araştırma Programı kapsamında bir Avrupa Projesi geliştirilmiştir. Uluslararası düzenlenen proje konsorsiyumunda Avusturya, Almanya, İsveç, Türkiye, Slovenya, Şili ve Brezilya bulunmaktadır. Disiplinler arası köprü oluşturan bu proje, üniversiteler, araştırma kurumları ve sanayi ortakları tarafından desteklenmektedir. İlgili alanda önemli deneyime sahip katılımcılar, WoodWisdom - Net Araştırma Programına, ERA- NET WoodWisdom - Net 2 projesi çerçevesinde kabul gören bu orman tabanlı uluslararası araştırma ve geliştirme (Ar-Ge) projesini sunmuşlardır. Her ülke kendi ulusal finansman kuruluşları tarafından desteklenmektedir. Türkiye Bilimsel ve Teknik Araştırma Kurumu (TÜBİTAK), Türkiye'nin ulusal fon organizasyonudur. Uluslararası proje başlığı “The Application of Load Bearing Timber-Glass Composite Structures for Building Construction” olan proje, Türkçe başlık olarak “Ahşap-Cam Kompozit

Yapı Elemanlarının Bina Taşıyıcı Siteminde Uygulanması" adını taşımaktadır. Bu projede, deneysel olarak çalışmaları süren yük taşıma özelliğine sahip "ahşap-cam kompozit" kiriş, kolon ve perde duvar elemanlarının uzun süreli mukavemet ve atmosfer testleri ile yapıda kullanılabilecek pratik uygulama metotlarının oluşturulması ve kurgulanmak istenen taşıyıcı yapı sistemin ulusal veriler ışığında optimizasyonunu hedeflemektedir. Böylelikle yapı sektöründe kabul görerek mutedil yapı sistemleri ile rekabet edebilecek bir ürün elde edilmesi mümkün olacaktır.

Bu araştırma projesi kapsamında,

- Ahşap-cam kompozit yapı elemanının optimizasyonu ve geliştirilmesi,
- Ahşap ve cam kesitlerinin minimize edilmesi,
- Ahşap eleman mukavemetine göre araştırmaların yapılması,
- Farklı endüstri kurumları arasındaki çalışma ortamının uluslararası AR&GE projesi ile geliştirilmesi,
- Yenilenebilir kaynaklara dayalı, çevreye duyarlı taşıyıcı sistem modüllerinin yaratılması
- Düşük enerji ile üretilen malzemelerin kullanımı ile karbondioksit salınımının azaltılması (enerji tasarrufu),
- Geri dönüşümlü ve bina içerisinde değiştirilebilir yapı elemanlarının kullanımının geliştirilmesi,
- Kompozit sistemler için yeni ancak bilimsel dayanaklı tasarım kodlarının ve standartların oluşturulmasına öncülük edilmesi de amaçlanmaktadır.

Projenin çalışma etaplarında; küçük ölçekli numunelerin boyutlandırılması ve bu numunelerin laboratuvar ortamında deneyleri (aderans, kayma ve durabilite deneyleri) yapılmış, orta ölçekli numunelere dış ortamda uzun süreli yükleme, büyük ölçekli numunelere de yatay yüklemeler yapılmış (monotonik ve çevrimsel yüklemeler) ve taşıma kapasitesileri ölçülmüştür ve son olarak da pilot projeler tasarlanmıştır. 15 Aralık 2011-15 Aralık 2014 tarihleri arasında gerçekleşen proje, 3 yıl sürmüştür.

Araştırma projesi kapsamında yazılan bu tez altı ana bölümden oluşmaktadır. Giriş bölümü, çalışmanın amaç ve kapsamını anlatmaktadır. İkinci bölümde, projede yer alan ahşap, cam ve yapıştırıcı malzemeler üzerine geniş kapsamlı bir literatür taraması gerçekleştirilmiş ve konuyla ilgili mümkün olduğunca çok veri toplanmaya çalışılmıştır. Üçüncü bölümde, ahşap cam kompozit yapı elemanlarının, deprem gibi yatay yükler ve çevresel etkiler altında uzun süreli davranışları deneysel çalışmalar ile incelenmiştir. Dördüncü bölümde, deneysel sonuçlardan elde edilen veriler ışığında pilot proje uygulama önerileri tasarlanmış ve mimaride de ahşap-cam kompozit taşıyıcı yapı elemanları çekici bir alternatif yapı elemanı olarak gösterilmiştir. Beşinci bölümde, ahşap-cam kompozit yeni yapı elemanın piyasaya tanıtılması ve diğer yapı sistemleri arasında yer alması için ahşap ve cam endüstrisiyle yapılan piyasa anket çalışmalarına yer verilmiştir. Altıncı bölümde, çalışmanın sonuçlarına göre elde edilen değerlendirmelere ve gerekli önerilere yer verilmiştir.

Ekolojik yapıların vazgeçilmez malzemesi olan ahşabın kullanım alanlarının arttırılması ve cam kullanımının, beton ve çelik ile beraber kullanılmasının dışında özendirilmesi beklenen sonuçlardan biridir. Yüksek rekabet gücüne sahip, çok

değerlikli bir yapı sistemin oluşturulması olası sonuçlarından en önemlisidir. Ahşap ve cam kompozit elemanının üretimi için ağır sanayiye ihtiyaç olmaması da önemli bir özelliktir. Tam aksine bu kompozit elemanlar hızlı ve düşük enerji sarfiyatı üretim teknikleri ile imal edilebileceklerdir. Yapılan piyasa araştırması anketleri, ahşap-cam kompozit yapı elemanlarının kullanım alanı bulabileceği kanısını desteklemektedir. Bu yeni kompozit yapı teknolojisi, kış bahçeleri, cephe elemanları, prefabrike evler, seralar, ofis binaları, okul ve yuvalar, asansör şaftları, küçük objeler, bölme duvarları uygulamaları ya da tarihi binaların çevresel etkilerden korunması amacıyla yapılacak strüktürlerle ile kullanım alanlarını bulacaktır.

1. INTRODUCTION

1.1 Topic introduction

Timber and glass hybrid elements meet modern architecture´s demands and can help increase the use of timber as building material as well as the statically use of glass panes and plates.

Timber is widely used in construction industry, older than concrete and steel. In the beginning, the techniques used in timber construction based on experiences gained by practices, then the developments in engineering sciences effected timber construction techniques as well. Timber being a sustainable building material, it provides attractive detailing and natural appearance. Timber construction is adaptable not only to the traditional, contemporary building styles but also to the most futuristic ones. Its architectural possibilities are limitless.

Glass is known for many centuries and used in buildings very early due to its exceptional transparency. Nowadays, glass is being increasingly used as a structural material. The basic problem of glass is its unpredictable and brittle failure behaviour.

The main idea of the thesis is combines these two materials together to provide the best properties of the composite and utilise them as a structural element.

In this research the load bearing capacity of glass when combining timber is investigated and an appropriate method to combine them are finded. The composite elements allow the best of the characteristics of two different materials to be brought together for a common purpose. The main properties of this composite system is that timber provides ductility and glass offers resistance and stiffness (Cruz and Pequeno, 2008). The bonding system is also very important, because the adhesive brings together strength and flexibility.

This is one of the major reason for carrying out the presented experimental research. This thesis focuses on the analysis of experimental tests of timber-glass and

adhesives in terms of long term behaviour and load bearing capacity under cyclic and monotonic loadings.

These tests are being carried out as part of the EU Wood Wisdom-Net research project, “Load Bearing Timber Glass Composites (LBTGC)” with participants from Austria, Brazil, Chile, Germany, Turkey, Sweden and Slovenia.

Scientific and the Research Council of Turkey (Tubitak) is the national funding organisation of this project which number is 11O950 in Turkey. Along the project, the partners coming from different fields are worked together in order to combine their expertise and exchange knowledge related to each specific material with this significant international cooperation. The project intends to develop a building system composed of glass and timber sections. It includes design concepts, feasibility studies and performance assessments of the components in order to improve the overall performance. It also includes the development of new design calculations as well as the optimization of manufacturing methods. In this context, based on the research project, different size specimens are developed as composite elements made of timber glass and adhesives. Tension and shear tests are carried out on small size specimens. Medium size specimens are exposed to long-term loading at outside conditions. Then large size specimens are tested under monotonic and cyclic lateral load.

1.2 Aim and limitations

In this master thesis, timber and glass properties are surveyed for clear understanding of their advantages and disadvantages and analyse the stability of the ‘timber-glass shear wall element’ under loading. The second aim of the research behind this thesis has been to encourage to the knowledge about the possibilities of structural timber/glass composites required for the construction market to be inclined to produce and use such products in modern architectural buildings.

The structural element prototype, a shear wall based on a glass pane glued onto a timber frame was presented in this survey. A theoretical background of failure due to instability of structures is also important to obtain. This is achieved by an introductory literature review.

1.3 Outline of the thesis

Firstly, a literature review of the materials timber and glass, timber/glass adhesive bonds and components is given in Chapter 2. The timber and glass's properties are researched in phsical and mechanical sides and the positive and negative sides of these materials are researched thoroughly. Chapter 3, summarizes previous experimental laboratory studies under seismic loading conditions and experimental tests of displacements of large size specimens are analysed under monotonic and cyclic lateral loadings. The damage of the specimens are inspected closely and failure modes are established in these tests. Test results for the environmental and long-term loading effects on medium size specimens are also given in Chapter 3. Pilot projects which provide the possibility to experience the practicality and applicability of developed composite systems, and create different design and application solutions are described in Chapter 4. In Chapter 5 the results of survey, prepared by the market, is presented and discussed. Finally, conclusion and references are presented in the last chapter.

2. SURVEY OF LITERATURE

2.1 Timber as a Material

Timber is an efficient natural building material and has series of positive effects within the eco system which play an ever greater role in conjunction with the foundation for all our lives: the Earth. It is generally known and accepted that a prudent use of the Earth's resources is essential if we are to guarantee a sustainable development for the future (Kolb, 2007).

Carbon dioxide is the main contributor to the greenhouse effect. Growing trees soak up great quantities of carbon from atmospheric carbon dioxide (CO2), widely regarded as a greenhouse gas that traps heat and affects global climates. Timber is renewable, recyclable, and biodegradable—characteristics generally accepted as good for the environment.

The beginning of seventies of the 20th century brought a new view for influence on human activity in relation with the existing environment. With the development of the notion of sustainability, timber again came to the attention of construction industry due to its ecological values.

2.1.1 Structure and General Properties of Timber

This chapter includes the description of timber as a fibre composite material on a micro scale. Furthermore, timber material properties are defined within the general use of timber in construction.

2.1.1.1 Structure of Timber

Timber is a sawn timber, a material obtained from trees. They have a carrying system, consisting of root, trunk and branches. Trunk stands against the effects of gravity and wind, and transmits the minerals that root sucks, to the top of tree. Root sucks the water and minerals required for tree, by spreading to the deeps of ground.

Branches supports the leaves that perform the chemical reactions to create sugar and cellulose, essential to growth of tree (Eurode 5, 2007). When the cross section of tree is examined **(2.1)**, two particular main section can be seen: *The outer bark* which protects the tree against fire, rain, impacts, bug attacks and prevents it from excessive loss in moisture; *the inner bark* which transfers sugar, the most important nutrient, to the growing parts of tree.

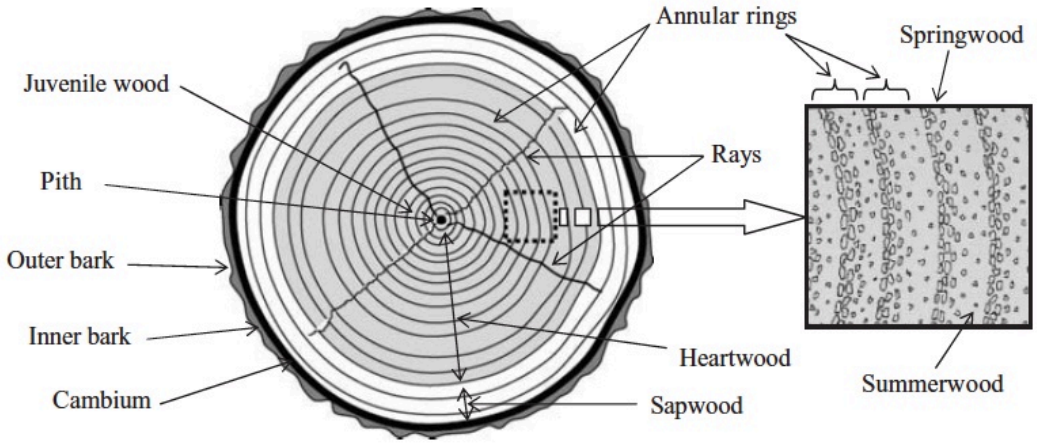


Figure 2.1 : Cross-section of tree trunk (Eurode 5, 2007).

In the timber section, there are rings that are nested around a pith. Pith is at the center of tree and similar to a thin, dark-coloured ribbon. Outer sections closed to bark, are light-coloured; inner sections closed to pith, are dark coloured. Dark or light, dull or bright lines can be seen from the pith to surface (Kuklik, 2008).

The cross section has a light-coloured outer part, *sapwood* which consists of new cells, which delivers water and nutritious materials vertically from root to leaves whereas a dark-coloured inner part, *heartwood* don't take part in nutrient, water transition, just provides rigidity to tree (Miller, 2007).

Rings that are nested around pith, *annual rings* width can be critical in respect of strength in that excess width of such rings can reduce the density of the timber (Kermani, 1999). The *cambium* in the bark provides transversal growth and cells to be formed by the growth effect of hormones, called auxin (Kuklik, 2008).

2.1.1.2 Defects in Internal Structure of Tree

Defects can cause trouble in timber in use either by reducing its strength or impairing its appearance.

Knots

A knot is a portion of a branch enclosed by the natural growth of the tree, normally originating at the centre of the trunk or a branch. The influence of knots depends on their size, shape, frequency and location in the structural member (Eurode 5, 2007). They have adverse effects on most mechanical properties of timber as they distort the fibres around them, causing non-uniform stress distributions. The resistance of element drops as the rate of knots increases at the section of timber (Miller, 2007).

Fiber

It defines the longitudinal array of all of cells in the tree trunk. The thickness of the fiber cell wall is the major factor governing density and mechanical strength of hardwood timbers. Commonly ordered lengthwise, fibers may not be proper due to abnormalities in the growth of tree. Loss of the regularity of fibers, causes the declination in endurance against axial charges, especially bending (Barrett, 1974).

Cracks

Depending on the loss of water in timber, cracks may occur anywhere on the surface and that causes to decrease the resistance of timber significantly **(2.2)**.

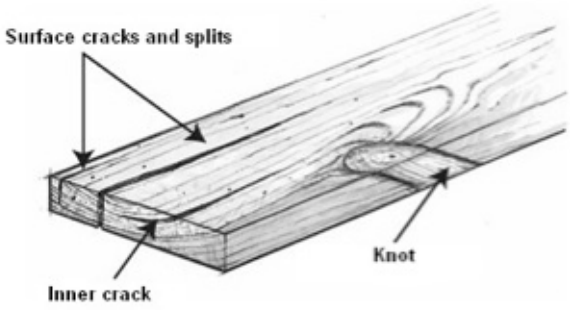


Figure 2.2 : Defects of timber (www.woodmagazine.com).

2.1.2 Types of Timber

Timber is generally divided into two groups; softwoods (conifers) and hardwoods (broad leaf). The distinction between the two is purely a botanical one and does not indicate density or toughness of tree. On the contrary, there are some hardwoods with low density and also some softwoods with high density.

For example, softwoods such as longleaf pine and Douglas-fir are typically more dense than the hardwoods basswood and aspen (Madison, 2010).

Softwoods are generally evergreen with needle-like leaves (such as conifers) comprising simple cells called tracheids , which are like straws in plan, and they fulfil the functions of conduction and support.

Softwood characteristics:

. Quick growth rate (trees can be felled after 30 years) resulting in low-density

timber with relatively low strength.

. Generally poor durability qualities, unless treated with preservatives.

. Due to the speed of felling they are readily available and comparatively cheaper (Kermani, 1999).

Anatomically, hardwoods are porous; that is, they contain vessel elements (or pore) which serve as a conduit for transporting water in the tree. Their anatomic structure is more complicated than softwoods due to their wide vessels of nourishment (Madison, 2010).

Hardwood characteristics:

. Hardwoods grow at a slower rate than softwoods. This generally results in a timber of high density and strength.

. There is less dependency on preservatives for durability qualities.

. Due to time taken to mature and the transportation costs of hardwoods, as most are tropical, they tend to be expensive in comparison to softwoods (Kermani, 1999).

The principal indigenous species of timber used for loadbearing constructions are as follows:

Softwoods: Spruce, Fir, Scots pine, Larch, Douglas fir

Hardwoods: Oak, Beech, Chestnut, Birch (Kolb, 2007).

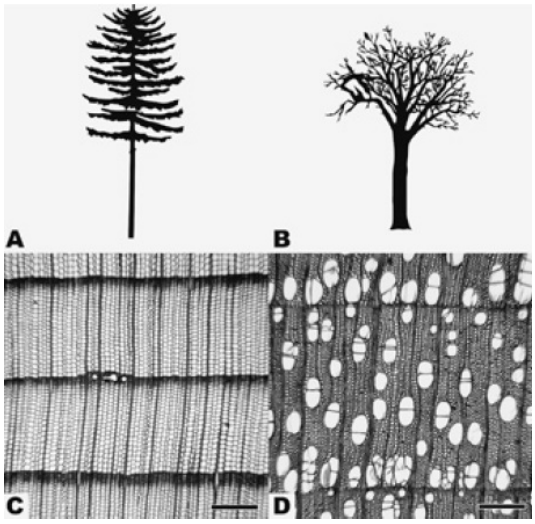


Figure 2.3 : (A) The general form of a generic softwood tree
(B) The general form of a generic hardwood tree
(C) Transverse section of typical softwood
(D) Transverse section of a typical hardwood
(Rowell, 2015).

2.1.3 Physical Characteristic of Timber

Physical characteristic as the rate of humidity, density, specific weight, void ratio, expansion-shrinkage and colour-fragrance will be examined.

2.1.3.1 Colour and Odour

Qualities such as colour, fiber structure, texture, brightness and smell give a general idea about the physical qualities of the timber. Secondary substances in the cell membrane give the timber its colour. Red, white, yellow, brown, crimson and similar colors which vary according to the type of the timber are important in decoration and furniture. Every healthy timber has a unique smell because of its chemical and biological structure. Natural smell is a quality which indicates the health status of the timber. It is concluded that there is a structural deterioration in the wood which has lost its smell. Suberized, damaged and decayed timber lose its smell. Because of these reasons, smell is an important norm in the quality control of the timber (Karabulut, 2000).

2.1.3.2 Thermal Conductivity

Timber is a material which is insulator against heat and cold because of air spaced texture in porous interior structure. It has a high resistance to heat flow. However thermal conduction quality varies according to the type and fiber direction of the

timber. Timber conducts heat more in vertical fiber direction compared to parallel fiber direction. It has considerably better thermal insulation properties than many other building materials (Faherty, 1998).

2.1.3.3 Sound Transmission

Well dried and well grown fibered healthy timber would create a clear sound when knocked on and the sound is transmitted without any disturbance. On the other hand, a wet and diseased timber would create a hoarse sound. Timber has also good acoustic absorption properties. It is being used in wall and ceiling covering of places such as cinema, concert halls, meeting rooms because of its quality of reflecting sound waves (Bardavit, 1992).

2.1.3.4 Moisture Content

Moisture can exist in timber as free water (liquid water or water vapor in cell lumina and cavities) or as body water (held by intermolecular attraction within cell walls). Timber changes dimensionally with change in moisture below its fibre saturation point: it shrinks when it loses moisture and swells as it gains moisture. This event is expressed as "movement of timber" because of its living structure (Eriç, 1994).

The process of drying (seasoning) timber should ideally remove over a third of the moisture from the cellwalls. Timber at this stage is referred to as seasoned with a moisture content of between 12 and 25% (Eurode 5, 2007).

Rate of humidity in timber equals to proportion of the water weight in wood(W_{water}), to the weight of dry wood(W_{dry}) (Ozelton, 2006):

$$Rate\ of\ Humidity\ (\%) = \frac{Water\ weight\ in\ wood\ (W_{water})}{Ovendry\ weight\ of\ wood\ (W_{dry})} \times 100 \qquad \textbf{(2.1)}$$

The water amount in the timber has a role on resistance qualities of the material, elastic modulus, stiffness, process capability, heating value, thermal conductivity, resistance against decaying and ageing to a certain extent. The change in moisture content of timber also effects its strength, stiffness and resistance to decay. Also it is effective in drying, preservation, polishing and bending procedures. Therefore it is important to know the relation between timber and water and to determine the moisture content in the timber (Bozkurt, 1996).

2.1.3.5 Density and Specific Gravity

Specific gravity varies according to the type of the timber and part that it is carved out from the lumber. Timber density equals to 320-720 kg/m^3, depending on type of tree. For a hydroscopic material such as timber, density depends on two factors: the weight of the timber structure and moisture retained in the timber. Timber of high density is stronger and stiffer than low density timber (Simpson, 2007).

Specific gravity provides a relative measure of the amount of timber substance contained in a sample of timber. It is a dimensionless ratio of the weight of an ovendry volume of timber to the weight of an identical volume of water (Winandy, 1994).

2.1.3.6 Timber Defects

Defects in timber, whether natural or caused during conversion or seasoning, will have an effect on structural strength as well as on fixing, stability, durability and finished appearance of timber (Kermani, 1999). To enhance the durability, timber can be treated with the preservative chemical treatment.

2.1.3.7 Dimensional Stability

Timber changes in dimension as moisture content varies below the fiber saturation point. It shrinks as it loses moisture below the fiber saturation point and swells as it gains moisture up to the fiber saturation point.

Shrinkage ratio is calculated by this formula (Yilmaz, 2011):

$$Shrinkage\ (\%) = \frac{Moist\ dimensions - Dry\ dimensions}{Dry\ dimensions} \times 100 \qquad \textbf{(2.2)}$$

Dimensional stability of timber is one of the few properties that significantly differ in each of the three axis directions (Winandy, 1994).

Longitudinal shrinkage: 0.1 – 0.3 %,

Radial shrinkage: 2.1 – 7.9 %,

Tangential shrinkage: 4.7 – 12.7 %.

Generally, tangential shrinkage (depending on species) is twice that of radial shrinkage.

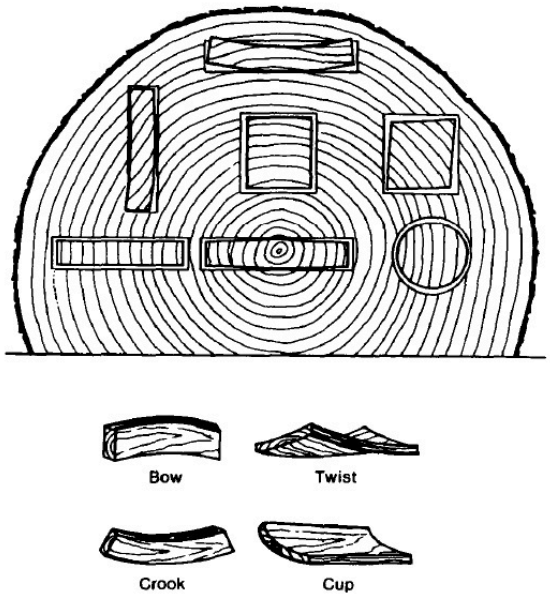


Figure 2.4 : Characteristic shrinkage and distortion of timbers as affected by direction of growth rings (Winandy, 1994).

The combined effects of shrinkage in the tangential and radial axes can distort the shape of timber pieces because of the difference in shrinkage and the curvature of the annual rings.

2.1.4 Chemical Characteristic of Timber

Basic components of dry timber are cellulose, hemicellulose, lignin and side materials.

Cellulose: Forms the walls of cells in tree, thus it is the most common material with a 40-50% rate in softwoods and hardwoods (Ridout, 2001).

Hemicellulose: Related to cellulose, consists of seven particular low-weight sugar polymers and have a rate of existence in tree as 20-35%.

Lignin: Consists of three dimensional phenylpropanol polymers combining cells(like grout). It is largely responsible for the strength of timber which exists with a rate of 23-33% in softwoods, and 16-25% in hardwoods (Graham, 1989).

Side materials: Fluid compounds such as resin, gum or fat. Its rate of existence is variable depending on the type of tree (Miller, 2007).

2.1.5 Mechanical Characteristic of Timber

The qualities which indicate the resistance level and state of timber against mechanic external forces and various stresses that change size and shape, create tension and breaking are named as mechanical characteristics. The resistance of timber against the effects of external forces is up to the capacious of the effecting force or the capacious of the load, to their direction, type and duration. Also qualities such as the shape, size and tension of the surface which is exposed to the loaded force affect the resistance (Karabulut, 2000).

Timber may be described as an orthotropic material; that is, it has unique and independent mechanical properties in the directions of three mutually perpendicular axes: longitudinal, radial, and tangential. The longitudinal axis L is parallel to the fiber (grain); the radial axis R is normal to the growth rings (perpendicular to the grain in the radial direction); and the tangential axis T is perpendicular to the grain but tangent to the growth rings.

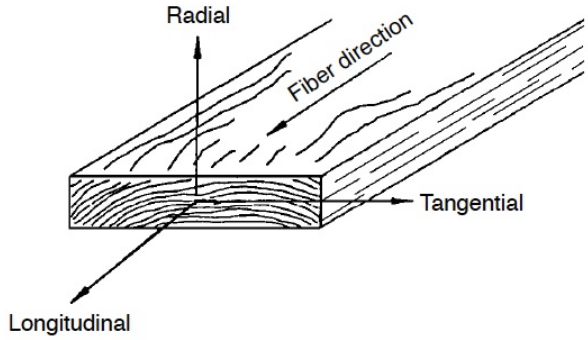


Figure 2.5 : Three principal axes of timber with respect to grain direction and growth rings (Green, 1999).

Futhermore, the material's degree of being affected from mechanical forces could vary substantially according to the climate, type of the timber, specific gravity, anatomic structure, moisture content, heat, if the material has defects or not and the angle between the effect direction of the force and the direction of the fibers.

Mechanical characteristic as the pressure and tension parallel to fibers, compression perpendicular to fibers, shear strength, modulus of rupture and modulus of elasticity will be examined.

2.1.5.1 Strength in Tension

It shows considerable differences if loading is axial (parallel to grain) or transverse. Strength in axial tension is much higher (up to 50 times and more) than perpendicular to the grain. Axial tensile strength of timber compares satisfactorily with metals and other materials. Axial tensile strength is greatly reduced by the presence of knots, spiral grain, or other growth abnormalities. The development of transverse tensile stresses is carefully avoided in timber structures, because the strength of timber loaded in that manner is very small (Tsoumis, 1991).

2.1.5.2 Strength in Compression

Compressive strength is the ability of timber member to resist load which are crushing the timber member. It is an important characteristic in posts, columns, piles, and truss chords and in those web members of trusses that are subjected to compressive stress. The strength of timber in compression is also different if loads are applied parallel or transverse to the grain. Axial compression strength is higher (up to about 15 times) than transverse to the grain. The strength of timber in axial compression is smaller in comparison to metals, but higher in comparison to most other construction materials such as brick and stone (Tsoumis, 1991).

2.1.5.3 Modulus of Elasticity

Elasticity implies that deformations produced by low stress are completely recoverable after loads are removed. When loaded to higher stress levels, plastic deformation or failure occurs (Green, 1999). The value of modules of elasticity of timber varies between 2500-17000 N/mm2. Timber has a lower modulus of elasticity than other materials; however if weight is taken into consideration, timber is comparable to steel, modulus of elasticity is different in the three growth directions. The above values apply to the axial direction, whereas transverse values are only 300-600 N/mm2. There are no differences between radial and tangential directions (Tsoumis, 1991).

2.1.5.4 Modulus of Rupture

Modulus of Rupture, frequently abbreviated as MOR, reflects the maximum load carrying capacity of a member in bending (Green, 1999).

2.1.5.5 Shear Strength, Shear Modulus

Shear strength is in general understood as the resistance of a timber specimen against a shear load on the surface of the specimen in direction parallel to the grain combined with a compression load perpendicular to the shear load. The shear modulus is in general evaluated with a 3-point bending arrangement (Köhler, 2007).

The mechanical properties of timber depend on the moisture content. An increase in moisture leads to lower values for strength and stiffness properties.

Table 2.1 : Approximate change (%) of clear timber properties for a one-percentage change of moisture content (Hoffmeyer, 1995).

Material Property	Change (%)
Compression strength parallel to the grain	5
Compression strength perpendicular to the grain	5
Bending strength parallel to the grain	4
Tension strength perpendicular to the grain	2.5
Tension strength parallel to the grain	2
Modulus of elasticity parallel to the	1.5

2.1.6 Advantages and Disadvantages of Timber as a Building Material

The advantages of timber are more dominant in the aspects of its specifications (Kılar, 2001). These advantages can be written as below:

- Timber is an organic material and a renewable natural resource.
- Timber is environment-friendly material since its utilisation doesn't affect the nature negatively. Life cycle assessment studies also show that timber buildings have less embodied energy than structures made from steel or concrete, are responsible for less air and water pollution, and have a lighter carbon footprint. (www.woodworks.org, 2015)
- Timber doesn't change in extra heat. For example it doesn't expand with high temperature and freeze with low temperature.
- Timber is also lightweight material with a good strength to weight ratio. This facilities designing, transporting, fitting and handling cost.

- Timber is a material which provides thermal insulation.
- Timber has sound transmission, absorption and reflection properties.
- It carries superior aesthetic and acoustic properties.
- It can absorb shock and vibration effect.
- If it is exposed to tension successively, it doesn't crystallize and brittle.
- It is not damaged by diluted acid and base so doesn't rust. It is is resistant to corrosive environments.
- It has quick erection times and reduced site labour.
- Timber performs well in earthquakes and high winds – Because timber-frame buildings are lighter and have more ductility than structures built with other materials, they are very effective at resisting lateral and uplift forces.
- Timber is versatile and adaptable and timber design flexibility lends itself both to traditional and innovative uses. There are several ways of connection details such as with glue, nail etc.
- Timber design is restricted to some degree by building codes and regulations (Graham, 1989).

Some disadvantages can be written as below: (Kılar, 2001).

- Timber is a combustible material. Fire resistance is achieved by protective methods and the thickness of timber section, which provides a degree of protection.
- If timber absorbs water, it swells and when it dries it shrinks. So there is not only change in dimensions but also rotation in cross section.
- It is susceptible to decay and when exposed to excessive moisture.
- Unless the protection is done, timber can be exposed to bug-infested.
- The mechanic properties of timber are not the same in every direction. Therefore the direction is important factor for the resistance.

2.1.7 Timber Preservation

Timber is not resistant to vegetational (fungus species) and animal (insect and bacteria species) harmful livings, and environmental conditions; and under these affects it is rotted quickly and deformed physically, chemically and mechanically. All kinds of preventive or recovering processes for harm and harmful livings that deforms or demolish the properties of timber and timber manufactures are called "preservative" (TS 343, 2012).

Preservatives can be examined in two groups by their way of application:

- Surface-Spread Preservatives : Dyes and varnish.
- Deep-Penetrative Preservatives: Oils and Oil Compounds (The most important one is creosote) , Organic Solvents (Such as; Tributyl-tin oxide, Pentachlorophenol (PCP), Chlorinated hdrocarbons) and Water-Soluble Metallic Component Salts (Such as; ACA (Ammoniacal Copper Arsenate), Boron compounds) (Kılıç, 2007).

Cellular structure of timber is crucial in preservation at two situations:

- Firstly, taking out the air jammed in cells,
- Secondly, fluids penetrating inside of cells (Ordu, 2007).

In modern industry, timber preservation is applied in two ways:

- Non-pressure methods: Simple applications, such as brushing, chamber-dipping.
- Pressure methods: Need an installed equipment like a steel chamber enabling any size of timber to be put in, and a particular facility for vacuum-pressure process (İlter, 2010).

Drying to reduce the humidity of timber can prevent the formation of fungus, but it is not adequate for insect invasion. After the insects chew off inside of timber, they leave holes behind. Timber is broken off with one tiny impact. Therefore, preversation must be applied (Ayar, 2008).

2.2 Building systems in timber structures

In Turkey generally, reinforced concrete or masonry buildings are prefered. Buildings with timber structural systems used to be the most preferred ones before 1950, but now these structures are rarely preferred and are being forgotten. However in developing countries such as USA, Canada, Japan and Australia, timber constructions are frequently most prefered systems.

2.2.1 Traditional Timber Structural Systems in Turkey

Timber houses can be found mostly in rich forest areas, which are seen generally in northern, western and coastal parts of Anatolia (Günay, 1998). Himis and bagdadi systems which are the traditional structural systems, still widely being used in Anatolia.

2.2.1.1 Himis

This is a filled-in system, which is made by forming a bearing structure by means of fixing timbers on the foundation or on the heap (of rocks, adobes or timbers) and by placing adobes, rocks or bricks between these vertical and horizontal timber bearing elements and the frame that the beams form. Types of timber used in the bearing system have varied depending on regional characteristics. In Northern and North-Western Anatolia chestnut, yellow pine, ash tree; in West Anatolia oak, yellow pine; in Southern Anatolia cedar are generally used (Cobancaoğlu, 2001).

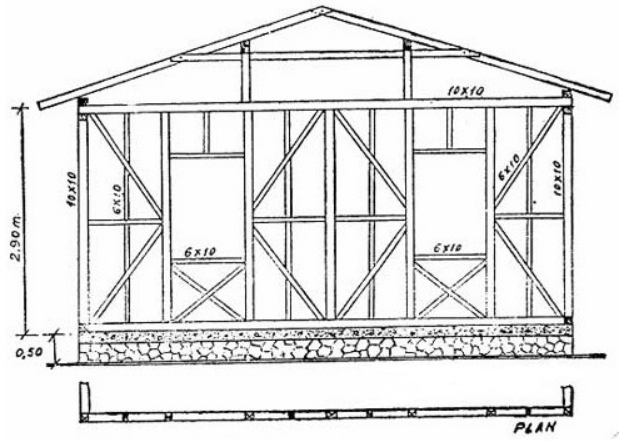


Figure 2.6 : Himis system (Cobancaoğlu, 2001).

2.2.1.2 Bagdadi

This type of technique is named as bagdadi is a kind of wall cladding which consists of timber laths having a width of 2-4 cm and a thickness of 2.5-3.5 cm. These timber laths are nailed to columns horizontally in both outer and inner walls with an interval of 2-3 cm (Doğan, 2010). The ductility and damping capacity is increased by the use of nails and laths. This type of structure is more refined from than himis.

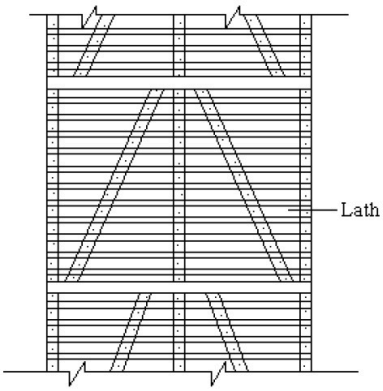


Figure 2.7 : Bagdadi system (Bayülke, 2001).

2.2.2 Timber Log Structures

Exterior walls in timber log structures are formed by overlap the massive timbers or laminated timbers. There is no need to coating the inner or outer wall surface in this system (Goetz, 1978). Timber buildings which created with log structures, carries a masonry feature and heavier than other construction systems. They are designed according to DIN 1052 (Design of timber structures, general rules and rules for building) and DIN 1055 (Actions on structures) standards (Avlar, 2002).

The features of log construction;

- Highly skilled labour
- Careful selection of timber
- Artistic corner joints
- Rigid plan layout
- High timber consumption (Kolb, 2007).

There are two types of log structures; columned and interlaced timber system.



Figure 2.8 : Sketch of the Log Timber Grove Meetinghouse drawn by Dorothy B.

2.2.3 Timber Frame Structures

The platform and balloon methods of framing are two ways of constructing a timber frame building (Anderson, 1992).

Timber frame system consists of load bearing frame (vertical, horizontal and diagonal members) and coating materials which fill in gaps of the frame. All structurally effective forces are transferred through frame members whereas insulating materials play no load bearing role. Coating part prevents external effects to harm the structure and plays the role of insulation against the heat, moisture and sound (Bardavit, 1992).

The features of timber-frame construction;

- The loadbearing framework can be clad on both sides, but traditionally it remains visible on the outside.
- Storey-by-storey form of construction
- Primarily timber joints with mortise and tenon and halving joints
- Structural timbers have a larger and usually square cross-section
- Simple assembly and erection
- Timber-frame construction don't cause large displacement and deformations under design external forces (Kolb, 2007).

2.2.3.1 Platform Frame

In platform frame construction, first floor joist are completely covered with sub-flooring to form a platform upon which exterior walls and interior partitions are erected (Details F., 2001).

This building system presents options for prefabrication, and allows for the use of standardised building components. Furthermore, it is a very flexible form of construction in terms of both design and architecture.

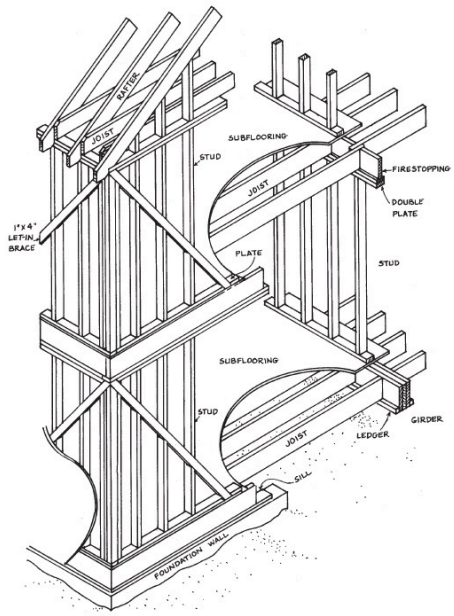


Figure 2.9 : Platform Frame (Details F., 2001).

2.2.3.2 Balloon Frame

In balloon framing construction, both the studs and first floor joists rest on the foundation sill plate **(2.10)** and the center beam or the bearing wall. As the space between the studs are not interrupted by wall plates (as in platform framing) .

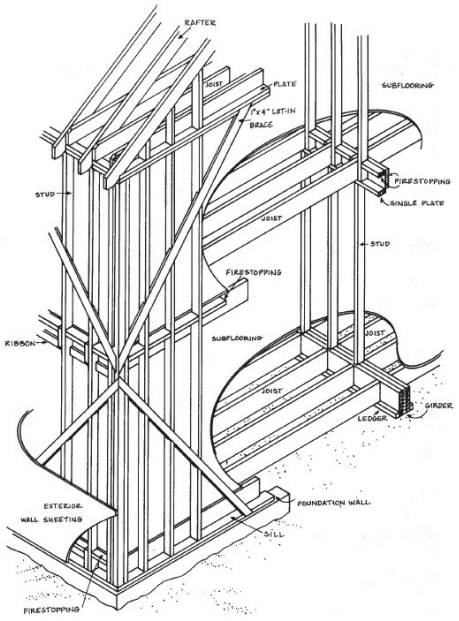


Figure 2.10 : Balloon Frame (Details F., 2001).

Connections between the floor joists and studs are not suitable for prefabrication. It constraints the design due to height of the wall panels (Çakir, 2000). The difference of balloon frame from platform frame is having wall panels are continuous through the building height. Continuous wall panels' size and weight cause difficulty during installation. Application area of balloon frame building method is not as common as platform frame in our day.

2.2.4 Timber Panel System

Timber panel system is formed by combining the panel of the elements. Timber studs (posts) are used in corner of combination timber panels (Avlar, 2001). Thanks to the standardisation of member sections, modular dimensions, connections and construction details, panel construction presents a simple timber building system. The features of panel construction;

- Design freedoms
- Simple form of construction
- Repetitive details
- Loadbearing ribs of slender, standardised sections
- Building braced by sheathing
- Simple materials procurement
- Storey-by-storey assembly
- Connections achieved by direct contact and with mechanical fasteners
- Short on-site time, different manufacturing depths possible (Kolb, 2007).

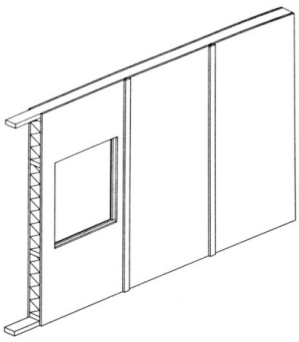


Figure 2.11 : Timber Panel System (Steiger, 2007).

Timber panel system is particularly suitable for single-storey buildings (schools, offices etc.). Less load bearing capacity and less fire resistance are disadvantages of this system. For these reasons, timber panel system application is limited by the two-storey buildings. The light weight, easy transportation and being economical are reasons to prefer this system (Goetz, 1978).

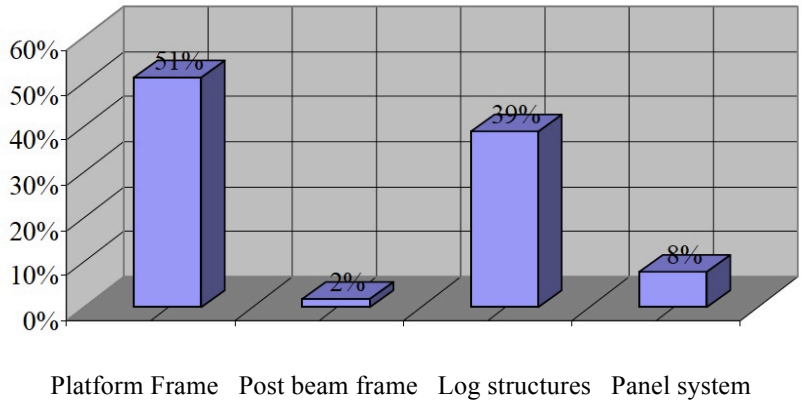


Figure 2.12 : Types and usage rate of load bearing system in timber building, Istanbul, (Erkoç, 2004).

As it can be seen from the figure, the platform frame is more used than other systems in Istanbul **(2.12)**.

2.3 Timber Composites

The term composite is being used in this chapter to describe any timber material adhesively bonded together. The basic element for timber-based composites is the fiber, with larger particles composed of many fibers. Elements used in the production of timber-based composites can be made in a variety of sizes and shapes. Typical elements include fibers, particles, flakes, veneers, laminates, or lumber. Timber composites are developed to overcome the limitations of sawn timber and are produced in combination with adhesives, in a variety of forms. They are:

- dried thin planks of timber are glued together to form glued-laminated timber or glulam;
- veneered, by peeling logs, and bonded together in different layouts to produce plywood or laminated veneer lumber (LVL);
- chipped, to different sizes, to produce fibreboards, chipboards or oriented strandboard (OSB);

- sliced in different forms to produce parallel strand lumber (PSL) and laminated strand lumber (LSL) (Eurode 5, 2007).

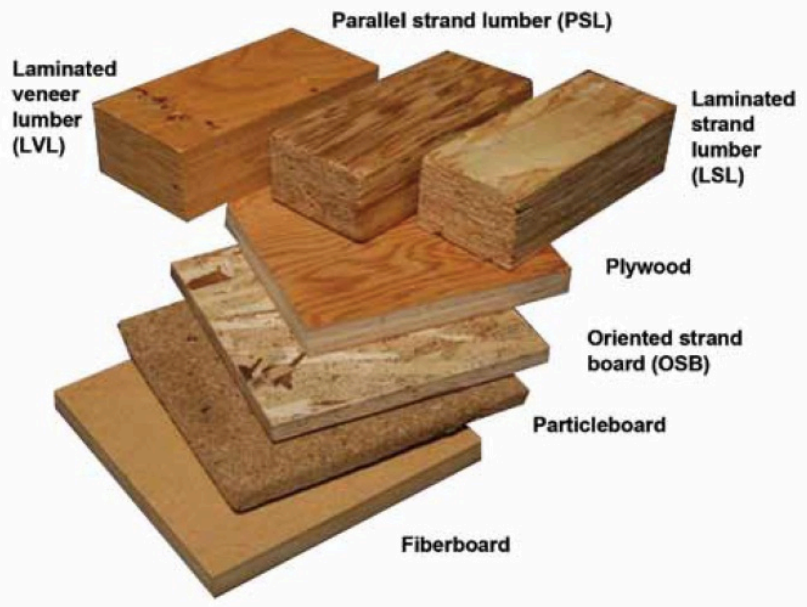


Figure 2.13 : Examples of various composite products (Madison, 2010).

The advantages of developing timber composites are to use waste timber from other processing, to remove defects, to create more uniform components, to develop composites that are stronger than the original solid timber, and to be able to make composites of different shapes. Swelling and shrinkage of timber-based composites are generally less than the solid timbers (Rowell, 2005).

Timber-based composites are used for a number of nonstructural and structural applications in product lines ranging from panels for interior covering purposes to panels for exterior uses and in furniture and support structures in buildings (Madison, 2010).

2.3.1 Glued-laminated Timber

Glued laminated timber is currently used for construction members and typically consists of at least four laminations of timber, bonded together with adhesives. The grain direction is parallel to the direction of the construction member. It is produced from strength-graded quality timber such as spruce. (Rowell, 2005) Compared with solid-sawn timbers, wider, deeper, longer and stronger beams can be manufactured with them (Shmulsky, 2011).

2.3.2 Structural Composite Lumber

Structural Composite Lumber includes laminated veneer lumber (LVL), parallel strand lumber (PSL), and laminated strand lumber (LSL). PSL is made from 3-mm thickness veneers and adhesive is applied to blocks under high pressure. LSL is similar to PSL, but cutting from logs is used in different way. LVL is closely related to plywood and is produced in larger quantities than PSL and LSL. In contrast with plywood, all veneer is typically oriented in one direction. It is often used for load-bearing panels.

2.3.3 Particleboard

Particleboard manufactured under pressure and heat from particles of timber (flakes, chips, shavings, sawdust and similar) and/or other lignocellulosic material in particle form (flax shives, hemp shives, bagasse fragments and similar) with the addition of an adhesive (EPF, 2015). The physical and mechanical properties of particleboards are mainly dependent on the properties of the raw materials (timber, binders, and other additives) and manufacturing parameters. Compression timber is one of the most important raw material variables in timber based panel manufacturing such as particleboard (Timell, 1986). Particleboards which are easy to work and flexible in application, used for timber furniture.

2.3.4 Flakeboard

Flakeboard includes waferboard (WB) and oriented strandboard (OSB). They are structural panels produced from wafers obtained from logs. In WB production, wafers fall randomly whereas in OSB production, wafers are mechanically oriented in one direction.

Plywood and OSB are competing materials for timber structural panels. The structural performance of the two materials is equal in general terms. For instance, they share the same exposure durability classifications, performance standards, and span ratings, but one limitation with OSB is edge swelling. Although the edges are coated during transport, subsequent cutting causes limitations in high humidity applications. It is prefable for its lower cost as compared with plywood (Rowell, 2005).

2.3.5 Fiberboard

Timber based timber products include hardboard (HDF), insulation board (LDF), MDF and a rapidly growing number of timber fiber-plastic composites. These products are manufactured from timber that has been reduced to individual fibers or fiber bundles that are formed into a mat, compressed and dried (Shmulsky, 2011). Fiberboard is a hygroscopic material; therefore, its moisture content depends on the relative humidity and temperature of the surrounding air. Linear expansion or contraction, in occurring response to increased or decreased moisture content of the material, is one of the most important properties of the fiberboards. Ayrilmis (2007) study showed that the dimensional stability of fiberboards were adversely affected by panel density. The linear expansion/contraction and thickness swelling/shrinkage increased with increasing panel density, principally in densities above 850 kg/m^3 .

MDF (Medium density fiberboard) typically has a density of 600–800 kg/m3 , while HDF (High density fiberboard) has a density of 800–1,100 kg/m3 . MDF is one of the most rapidly growing composite panel product in the market. Thanks to smooth and solid edges, MDF can be easily machined and finished, and the uniform surface provides an excellent substrate for painting or applying decorative overlays (Ayrilmis, 2007). Hardboard is generally used in the expanding laminate flooring market where a hardboard sheet is used as a backing for the laminate top layer. The major application areas are as insulating layers in exterior products (sheathing, roof insulation), interior products (building boards, ceiling tiles, and sound absorption boards) (Rowell, 2005).

2.3.6 Plywood

Plywood is a flat panel made by bonding of thin layers of veneer together under pressure. Each layer may contain one or more veneers according to the thickness of the board (8-33 mm). The grain of each layer is perpendicular to the grain of its next layer **(2.14)**.

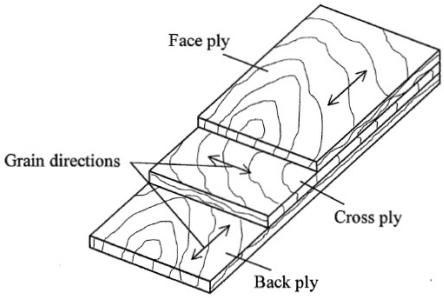


Figure 2.14 : The structure of a three-ply plywood (Kermani, 1999).

There are two types of plywood: softwood plywood and hardwood plywood. Softwoods generally correspond to coniferous species. The most commonly used softwoods for manufacturing plywood are firs and pines. Hardwoods generally correspond to deciduous species. For hardwood plywood, commonly used timber species include birch, oak, poplar, maple, cherry, and larch.

Hardwood plywood is used for interior applications such as furniture, cabinets, architectural millwork, paneling, flooring, store fixtures, and doors. Softwood plywood is used for wall siding, sheathing, roof decking, concrete formboards, floors, and containers (EPA, 2002).

The manufacture of softwood or hardwood plywood consists of nine main processes: log storage, log debarking, heating the logs, peeling the logs into veneers, drying the veneers, gluing the veneers together, pressing the veneers in a hot press, plywood cutting, and other finishing processes such as sanding. Moreover, the quality of the glue bond, which is of primary concern in plywood manufacture, is of vital importance to proper performance (Countryman, 1964).

The structural properties and strength of plywood depend on the number, thickness and the arrangement of each plies (grain orientation of the plies), the species of timber, quality or grade of veneer and type of adhesive (Faherty, 1998).

The moisture content of plywood is normally 7-12 % when leaving the mill. It may change during storage and transportation. Plywood is a hygroscopic product like other timber products and exhibits visco-elastic mechanical behavior. So, it is necessary to take measure for the moisture and to use the waterproof glueline. TS EN 322 specifies method for determining be moisture content of plywood and plywoods are classified on the basis of moisture resistance.

There are more advantages compare to the solid timber such as light weight, ease of working, ease in fastening, high strength-to-weight ratio and high shear strength. Plywood is used for a wide range of structural, interior and exterior applications (Such as doors, stairs, flooring, framing, wall and roof sheating, internal panelling, joinery product, beams, trusses, shearwall and reinforcement of timber structures), furniture production, transport sector, packaging industry and advertisement kiosk.

2.3.6.1 Standarts of Plywood

Standarts relevant to plywood can be cited as following;

BS 5268 : 1996 'Structural Use of Timber' deals with plywood for structural use. It gives characteristic values of mechanical properties for plywood in bending, based on a series of strength classes and modulus classes for structural system.

TS 4645 EN 636:2003 'Plywood Specifications' details the requirements for plywood for general purposes and structural application in dry, humid or exterior conditions.

BS EN 635 :1999 'Plywood Classification by Surface Appearance' specifies the methods for measuring and expressing some inherent characteristics of timber and some defects that come from the manufacturing process.

The characteristic values for plywood panels can be determined is given in BS EN 12369-2:2004.

TS 2128 EN 313 'Plywood, Classification and terminology' defines the principal terms concerning plywood and gives a classification of plywood panels according to their general appearance, their form and shape, their mechanical properties, their surface condition.

BS 314 'Plywood, Bonding quality' is identified in three classes that are dry, humid and exterior conditions.

BS EN 315 'Plywood, Tolerances for dimensions' specifies dimensional tolerances of plywood panels (length, width, thickness) and tolerances for squareness and edge straightness.

BS EN 14272:2011'Plywood. Calculation method for some mechanical properties' specifies a calculation method to derive some mechanical properties (strength and

stiffness in bending, tension, compression, panel and planar shear) as well as density from the wood compounding the layers.

BS EN 1381 ‘Timber structures- Tests methods - Load bearing stapled joints’ is determined experiment methods for the strength and deformation properties in timber load-bearing structure.

TS EN 13986 ‘Wood - based panels for use in construction - Characteristics, evaluation of conformity and marking’ It refers several properties and quality control procedures for different grades of panel. Properties are assessed in term of bending strength and stiffness, bond quality/internal bond, durability, moisture resistance with quality control test.

BS EN 335:2013 ‘Durability of wood and wood-based products. Use classes: definitions, application to solid wood and wood-based products’ is stated that plywood, particleboards, oriented strand boards, fibreboards, cement-bonded particleboards in relation only to the biological agencies that can attack wood-based panels over a duration sufficient to result in deterioration.

BS EN 338:2003 ‘Structural timber - Strength classes’ gives characteristic strength and stiffness properties and density values for each class and the rules for the allocation of timber populations (i.e. combinations of species, source and grade) to the classes.

BS 1088 ‘Specifications of plywood for marine’ specifies requirements for marine plywood for use in the manufacture of marine craft and in other waterway applications.

2.4 Examples of Timber Building Structures in Turkey

The most stunning example of course is the Rum Orphanage in Buyukada, largest of the Prince Islands of Istanbul. No doubt, it is one of the biggest timber buildings of its age that was built as a hotel in 1899, and then later altered to serve as an orphanage. The building is 23 meters high and sits on an area of 101x32 meters **(2.15)**.



Figure 2.15 : Rum Orphanage in Buyukada, Istanbul (www.uludagsozluk.com, 2015).

Another interesting building is “The Architect's Office" received the best building award of the Turkish Chamber of Architects in 2006 within the biennial National Architecture Exhibition and Awards Program. The architect’s office sits on the retaining walls, and these walls flow from inside the office into the landscape. On the west side the retaining wall is built as a double layer stone wall with a 40 cm cavity. The timber wall on the east side sits on a lower stone wall. The entire timber wall on the east is used as a bookshelf **(2.16)**. 5 cm foamboard is used for thermal insulation in the roof and in the walls **(2.17)**. 20 mm plywood and waterproofing membrane are laid on top of the foamboard. Rain water is drained to the ground through timber grills (Urbarama, 2015).



Figure 2.16 : Exterior and interior view of The Architect’s Office, Urla (Archive of Serhat Akbay).

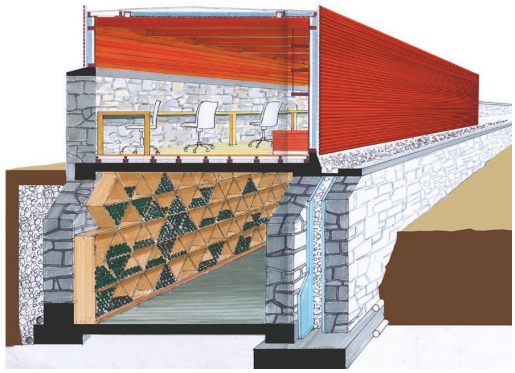


Figure 2.17 : System details of The Architect's Office, Urla (Archive of Serhat Akbay).

Another example is Ilyas Bey Islamic Social Complex, within the ruins of ancient Miletos (Palatia) open-air museum in Aydın. Timber roof construction was used by architect Şevki Pekin for protect to ruins of complex in 2010. Timber roof was carried through the timber trusses and connected to the ground with metal plate **(2. 18)**.



Figure 2.18 : Ilyas Bey Islamic Social Complex, Aydın (Archive of Şevki Pekin).

Further example, 'Ipera 25 apartment' was designed by Turkish studio Alataş Architecture & Consulting in Istanbul. Timber louvres and shutters form a protective shell are across the exterior of this apartment building **(2.19)**. The architects divided the wall into four long vertical strips, which project forward and backwards at different points to allow slices of glass to emerge from between each of the timber panels. The building is comprised of a timber shell that covers the largely transparent living area in an uncompromising manner and set between two blind and extremely thin exposed concrete curtain walls. The timber components on the front elevation run parallel to the glass facade that evolves into a saddle roof and entirely cover the front and back of the building. Perceived as a gigantic blind facade from one

perspective, yet appearing as a translucent veil from the other, the timber surface also functions as a sun filter. (www.dezeen.com, 2015)



Figure 2.19 : Ipera 25 apartment building, (www.dezeen.com, 2015)

Similarly, Suryapi Office Building sits on a hillside in a way people can perceive the facade of the building in Istanbul. The building was designed as the head office by the construction company, Tago Architects. The building has 2182 m^2-closed area, consist of 3 floors which are two basement floor and one ground floor. South façade is placed in front of a glass surface as a secondary facade. Geometric timber panels strengthen the perception of the building from the main road and the solid-void relationship brings a comfortable office ambiance by the control of sunlight and sound **(2.20)**. By the sharp geometric combination of the materials; timber, natural stone and glass are creating the general character of the building and this characteristic features are reflected on landscape design. (www.archdaily.com, 2015)



Figure 2.20 : Office Building In Istanbul by Tago Architects, (www.dezeen.com, 2015).

2.5 Glass as a Material

"Glass is arguably the most remarkable material ever discovered by man."

Wigginton M., 1996

Glass is ancient material which exists also in nature, in the forms of minerals. The history of glass manufacture dates back ancient times. Due to the development of different methods of glass manufacture, a wide range of glass types produced. Architects began to design buildings with more glass surface due to the increase of transparency and larger available glass pane sizes. Glass also provided some basic functions in structures, such as light transmittance, sound insulation, inner and exterior wall coverings and roof covering. It was also one of the rare materials used to provide complicated functions including multiple functions such as light transmittance, heat insulation, image display, safety, intended light transmittance etc. (Toydemir, 1990). With the discovery of glass strengthening methods, in the last few years glass began to also be a load bearing material for building construction.

In addition to this, glass is a very useful material in renewal projects (restoration), mostly older buildings, which have been rebuilt preserving the original details and materials. Its transparency makes it possible to 'open up' existing monumental buildings and make daylight and transparency a core value in the design to create a high quality environment (Van der Heijden, 2010).

2.5.1 Production of Glass

The main production of glass steps are always similar: melting at approximately 1600–1800 C^0, forming at 800–1600 C^0 and cooling at 100–800 C^0.

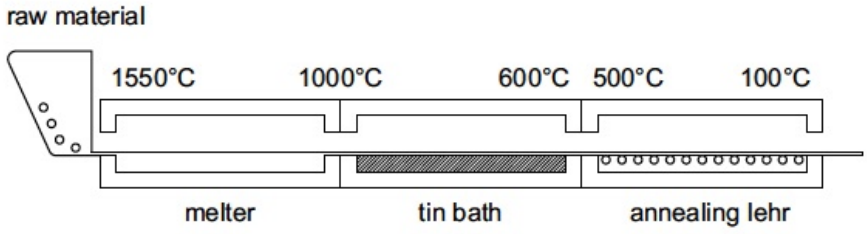


Figure 2.21 : Production of glass (Haldimann, 2008).

Firstly, the raw materials are weighed and mixed precisely.Then they are melted in a furnace at tempratures of up to 1800 C^0. The molten glass is poured over a thin bath which is cooler than the forming substrate. The tickness is also controlled. When the glass hard enough, it is driven on annealing lehr for cooling.

2.5.2 Structure and General Properties of Glass

2.5.2.1 Structure of Glass

Glass is composed of silicon dioxide (silica), which is present in the Earth's crust in the form of pure quartz sand. The glass former is combined with sodium oxide (soda), which acts as a flux to reduce high melting point of silica (app 1700 C^0). The melting point is above 1100 C^0 , it is amorphous (non-crystalline). Because the structure of glass resembles that of fluids, it is often called 'supercooled liquid'. Calsium oxide (lime) is also added as a stabilisier to increase chemical resistance. (Wurm, 2007) According to EN 572, the most commonly used soda-lime glass is composed SiO_2 69-74%, CaO 5-12% and Na_2O 12-16%.

Borosilicate glass, which contains boron oxide rather than calcium oxide, is often used as fire-resistant glass thanks to its high chemical and thermal stability.

2.5.2.2 Properties of Glass

The most important properties of glass are summarized in Table 2.2. Glass with a density comparable to reinforced concrete presents modulus of elasticity almost equal to that of aluminium. (Kozlowski, 2012)

Table 2.2 : Properties of the glass (Hess, 2004).

Density	25 kN/m^3
Young's Modulus	70000 MPa
Shear Modulus	28000 MPa
Poisson's Ratio	0.23
Hardness (Mohs scale)	6
Coefficient of thermal expansion	9 x 10^{-6} 1/K
Tensile strength	45 MPa
Compressive strength	800 MPa

Hardness of glass is between 6 and 7 with regard to Mohs hardness scale. Glass with a hardness at this level has a good resistance to abrasion. Softening temperature of glass is between 500-600 °C (Toydemir, 1990).

The strength of a glass is the ability to resist stress without failure. Such as; tensile, compression, bending and shear. It depends on the duration of loading, glass type, size and age of pane and surrounding medium (air moisture content) (Wurm, 2007).

Glass has a very high theoretical tensile strength, up to 45 MPa. However, the actual tensile strength depends on the influence of mechanical surface flaws. The compressive strength of glass is considerably higher than the tensile strength, since there is no surface flaw growth or failure under compression **(Table 2.2)**. Another factor that affects the strength is the roughness of the edges on the glass, a flat surface is much stronger. The edge finish is a dominating factor in determining the glass strength (Veer, 2003).

It shows isotropic and exhibits brittle fracture. In contrast to other construction materials, no plastic deformation occurs prior to failure. When loaded, glass shows a perfect linearity in the curve of stress versus strain with a Young's modulus of 70-75 GPa. All the deformations are elastic which means that the glass returns to its original shape when the force or stress is removed. But glass is stressed beyond its strength limit, breakage occurs immediately without warning, unlike steel and aluminum where plastic mechanism can be formed **(2.22)**. Stress or moment

redistribution does not occur in glass and then consequential global failure is very common in glass (Chan, 2006).

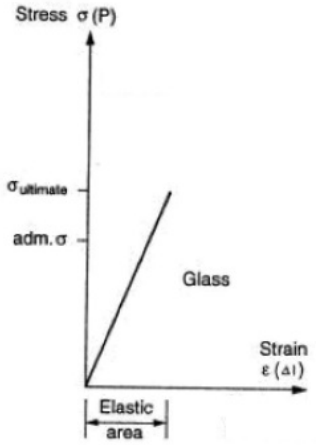


Figure 2.22 : Strees-strain of the glass (Wurm, 2007).

According to prEN 16612: 2013, characteristic value of the bending strength of annealed glass is 45 MPa. For prestressed glass, the characteristic bending strength value is 70 MPa for heat strengthened glass and 120 MPa for fully tempered glass.

Glass is highly resistant to acid and water, even salted. In building glass as an exterior is exposed to wet and dried conditions continuously so it can contact with water for a long time. It is one of the most durable materials in construction, due to its random and complex molecular structure.

Thermal conductivity coefficient of glass is 1 Kcal/m/h/ ºC which means relatively high (Toydemir, 1990). Thermal transmittance can only be reduced to meet modern thermal insulation requirements.

Glass is non-combustible but it is low resistance to differential temperatures. The tempered borosilicate glass has excellent thermal resistance due to its very low coefficients of thermal expansion. So it is used as fire-resistant glass. Fire-resistance glasses are classified according to EN 13501 'Fire classification of construction products and building elements' which rating for the period of times in fire (30 or 90 minutes).

The last properties of glass, acoustic, depend mostly on thickness of glass. Sound absorption is increased by using thicker glass.

2.5.2.3 Advantages and Disadvantages of Structural Glass

Glass is more vulnerable, difficult to handle and expensive than conventional structural materials like steel or concrete. Nonetheless, it is a very interesting material for building designers for two main reasons: transparency and strength.

Buildings, in which even the primary structure is transparent, closely approach the ideal of visual weightlessness of many architects. At the same time, more daylight can penetrate in the building, which has, according to specialised literature, a beneficial psychological effect on building users (Norris, 1997).

The brittleness of glass can be considered disadvantages of structural glass. It is clear that glass shows no plastic behaviour under normal temperature conditions If the plastic deformation limit is minimally exceeded, the glass breaks spontaneously (Belis, 2004).

2.5.3 Types of Glass

2.5.3.1 Float Glass

The float glass is the most commonly used form of basic glass. Its name derives from the process in production. As mentioned in the manufacture of glass, the molten glass floats bath of tin because of lower specific gravitiy. Thickness is also determined by the speed with which it is pulled over the tin bad. According to EN 572-2 ‘Glass in Building-Basic Soda Lime Silicate Glass Products-Part 2: Float Glass’, float glass is manufactured in thicknesses between 2 to 25 milimetres.

After float bath, float glass is slowly cooled in the annealing lehr. Thus, float glass is also called annealed glass. The slow, uniform cooling to room temperature results in much lower internal stresses of material that can be cut, drilled, edge worked, etc. (Behr, 2009) Annealed glass splits into large and dangerous fragments at breakage **(2.24)**.

2.5.3.2 Heat-treated Glass

Heat-treating is the next processing of float glass to improve its strength and alter its breakage behaviour. There are two kinds of heat treatment glass, heat strengthened glass and tempered glass (Patterson, 2011). These types of glass have different

cooling rate, therefore different compressive strength on their surface and different breakage patterns.

2.5.3.2.1 Tempered Glass

Tempered glass is occurred by applying further heat treatment to annealed glass under controlled conditions, then cooled very quickly. The surface and edges solidify rapidly while the centre is still in a fluid state. Parabolic residual stress field is observed which has tensile stresses in the core and compressive stresses at the surfaces of the glass during tempering process **(2.23)**. Typically, the pre-compressed zone is 20% of the total thickness of the glass on both sides. Thanks to the pre-compressed surface, when glass panels are loaded, the surface will retain compression and significantly reduces its brittleness.

Because of pre-compression, strength of glass is also improved under long-duration load. It is four to five times stronger than annealed glass.

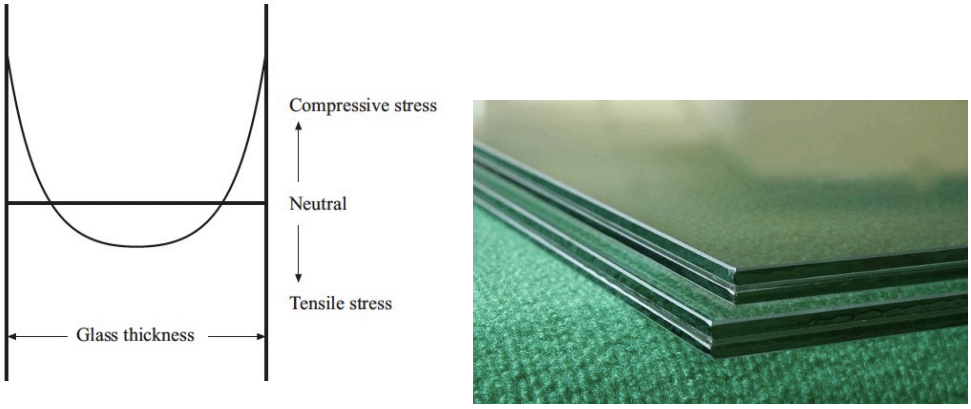


Figure 2.23 : The residual stress field in tempered glass (Bength, 2005) and the figure of tempered glass (Savic, 2013).

Tempered glass has highest residual stress level and usually breaks into small harmless pieces and therefore it is also termed safety glass **(2.24)**. Tempered glass, though more resistant to superficial stresses than laminated glass, presents two considerable and decisive disadvantages, such are brittle behaviour and an irregular surface (Cruz, 2008b). Due to the tensile stresses within the tempered glass, it can not be worked or cut after the tempered process. If worked, e.g. drilling a whole in the glass, it will fracture completely. For this reason, all treatment of the tempered glass must be done to the annealed glass in the industrial process.

2.5.3.2.2 Heat-strengthened Glass

Heat strengthened glass is produced similarly as tempered glass, but the cooled more slowly. It reduces the pressure on the surface, which results in both a different fracture pattern, lower bending and tensile strength than tempered glass (Achilles, 2009). Heat strengthened glass is two to three times stronger than annealed glass. It has a sufficiently large fragmentation pattern, but pieces are typically quite smaller than those found on breaking annealed glass **(2.24)**.

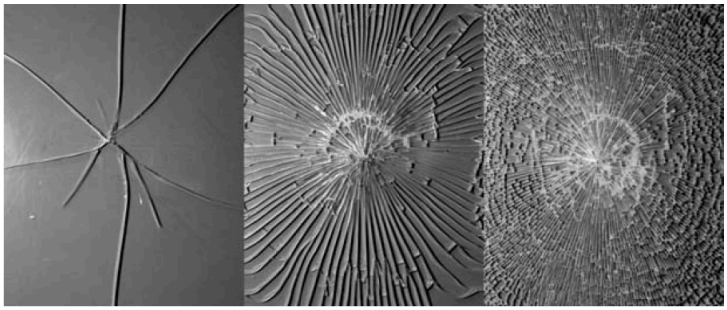


Figure 2.24 : Comparison of the fracture pattern: annealed glass (left), heat-strengthened glass (middle), fully tempered glass (right) (Haldimann, 2008).

2.5.3.3 Assemblies of Glass

2.5.3.3.1 Laminated Glass

Laminated glass is made by gluing two or more glass panes together with a plastic interlayer which is most often made of polyvinylbutyral, PVB. The viscoelestic PVB film is characterized by good adherence to glass, high tear strength and high transparency. The nominal thickness of a single PVB film is 0.38 mm but it can be made many times like 0.76 mm and 1.52 mm (Achilles, 2009).

The strategy of lamination provides glass with a kind of plasticity and ductility. The laminated glass has advantage that it holds the glass together even if a crack appears which can generate a remaining structure with some post breakage load bearing capacity after fracture has occurred. Because the glass fragments adhere to the film and keep residual strength.

Two factors affect the strength of laminated glass; the ability to transfer horizontal shear force (using PVB for this) and the thickness of the glass panes (Norville, 1997).

All basic products, heat strengthened glass and tempered glass can be laminated, although there may be restrictions on the laminating process used and size available. (Colvin, 1997). The post-breakage behaviour depends on the interlayer material **(2.25)**.

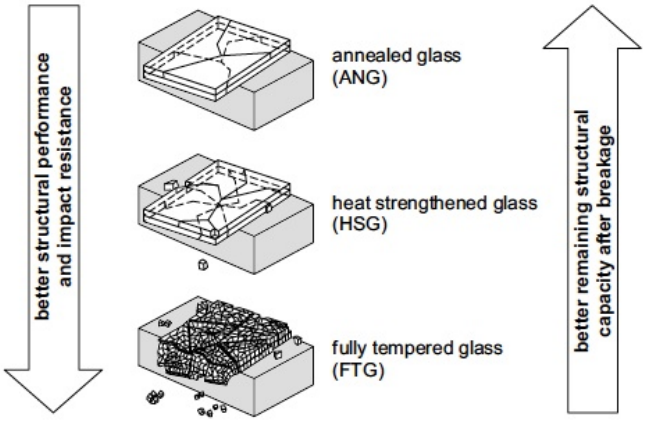


Figure 2.25 : Post breakage behaviour of laminated glass made of different glass types (Haldimann, 2008).

If the laminated glass is made from float glass, it is still workable like cutting and drilling.

2.5.3.3.2 Insulating Glass

An insulated glass consists of two or more glass panes with inert gas (argon, krypton, xenon) or air which sealed in the air space. The edge seal running around the pane consists of a spacer of aluminum, stainless steel or plastic and sealents (Achilles, 2009). Insulating glass provides thermal insulation, additional security and acts as sound barrier against the outside elements. There isn't necessary to increase the glass thickness for thermal insulation. It is relevant to airspace whose insulation increases by increasing the thickness (Paci, 1997). In addition, the air space between glass panes is also increased for the sound reduction. The other measure is using laminated safety glass with soundproofing films or vacuum layer (Minaai, 2007).

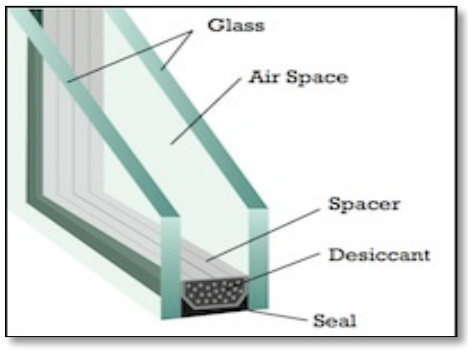


Figure 2.26 : Components of the insulated glass (www.glassdoctor.com, 2015).

Nowadays, a facade or window utilizing as double-glazed which need three glass panels with two hermetically sealed cavities, have become increasingly common.

2.5.3.4 Coatings

Coating the surface of the glass can significantly influence the optical, mechanical and psysical properties of the glass, depending on the requirements.

The coating is applied either during the manufacture of glass (that is online) or after manufacture is complete (that is offline). In the online coating, metal oxides (conductive oxide) are applied to the surface of the glass while in the offline coating, noble metal e.g. silver (high conductive metal) is used for solar reflective insulating of glass (Pulker, 1999).

Solar control coatings prevents much of radiant energy from inside by absorption and reflection of the radiation. Low-emissivity (low-e) coatings save energy and increase comfort inside a building by reducing heat loss towards the environment (Haldimann, 2008). Additional to the coating glass, there are number of ways to use in solar control, such as; body-tinted glass, laminated glass with tinted interlayer, insulating glass units,shading devices or combinations of them (Maniatis, 2008).

2.5.4 Standarts of Glass

Standarts relevant to glass can be situated as following;

ASTM C1048 ‘Standard specification for heat-strengthened and fully tempered flat glass’ defines fabrication requirements, tolerances and testing procedures for heat-treated glass.

EN 1863 ‘Heat strengthened soda lime silicate glass’ covers the evaluation of conformity and the factory production control of flat heat strengthened soda lime silicate glass for use in buildings.

EN 12150 ‘Glass in building- Thermally toughened soda lime silicate safety glass’ specifies tolerances flatness fragmentation and physical, mechanical characteristics of monolithic flat thermally toughened soda lime silicate safety glass for use in buildings.

EN 1096 ‘Coated glass’ defines the characteristics properties and classification of coated glass in Part 1, requirements and test methods related to artificial weathearing and abrassion of coatings in Part 2 and Part 3, also deals with the evaluation of conformity of coated glass in Part 4.

ISO 12543 ‘Laminated glass and laminated safety glass’ determine definitions and description of component parts, test methods for durability, dimensions, edge finishing and appearance of laminated glass.

EN 1279 ‘Insulating glass units’ contain dimensional tolerances and rules for the system description as well as long term test method and requirements.

ASTM C1048 ‘Standard specification for heat-strengthened and fully tempered flat glass’ covers heat-treated flat glass - kind HS, kind FT coated and uncoated glass used in general building construction.

2.6 Structural Glass Elements

Thanks to the transparency, glass is one of the most important and widely used construction materials, but its application has been restricted to being a planar load resistant enclosure material for thousands of years, and now is experiencing an innovative transition to being a primary load carrying structural material. Point load carrying glass columns, linear load carrying glass beams and walls as well as glass compression bars have been designed and built, especially in Western Europe, such as Germany, the Netherlands and the UK (Fu, 2010).

2.6.1 Glass Beams

Glass beams are mainly used to support glass roof and floors. It generally carry vertical gravitational loads but can also be used to carry lateral loads (e.g., loads due

to an earthquake or wind). Glass beam design is very flexible. Glass can be connected to almost all kinds of architecture elements, such as steel beams, masonry walls, concrete columns, glass columns and fins. Theoretically, it could be strong enough to support decks made of different kinds of materials.

Some existing buildings with glass beams are presented in Figure 27. Glass beams were supported with the reinforcement elements, then the capacity of pass the large openings can be developed.



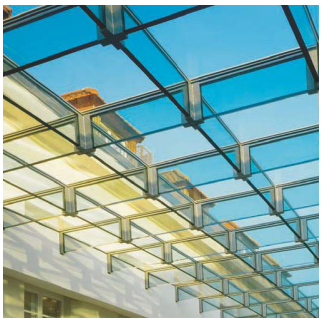
Wolfson Medical Building, UK, 2002.



International Chamber of Commerce, Munich, 2003.



Great Western Dock, UK, 2005.



Refectory at the TU Dresden, Germany, 2006.

Figure 2.27 : Buildings with glass beams (Wurm, 2007).

Furthermore, hybrid elements enable more efficient functionality of structural glass beams which are combined with ductile material; timber. Kreher, (2004) published research on timber-glass composite beams including float, heat-strengthened and fully tempered glass **(2.28)**. The timber flanges bonded to the tensile side of the beam acted as a reinforcement. The tests proved that the timber flanges increased the stiffness of the beam and were suitable as a load introduction and support. This allowed ductile structural behaviour of composite beams and increased residual strength up to 300 %.



Figure 2.28 : Timber glass beams in conference room (Kreher, 2004).

Load-bearing glass beams are usually described as brittle fracture due to excessive tensile stresses. Beams are mostly subjected to bending under the these stresses. Bending stresses depend on the span and the type of support. It means bending moment decreases when the span reduces with support. The moment of inertia increasing with the width and particularly the height of cross section resists the bending moment (Wurm, 2007). It is also observed the PVB interlayer of laminated glass beam was increased and then the flexural bending stresses in glass was therefore reduced in Norville (1998) experiment which set up an analytical beam model that explains deflection and stress for simply supported laminated glass beams under uniform load. This result in, the strength of a laminated glass beam is higher than that of a monolithic glass beam with the same nominal thickness.

2.6.2 Glass Columns

Columns usually stand in the way and they block the view. Nowadays, glass columns are more attractive for architects, due to the maximum transparency. Column is a linear loadbearing element that is primarily loaded in compression. Glass under increasing axial compression are deformed elastically until its collapse. It is advisable to make a column using toughened, pre-compressed glass and in such cases protective laminations is also applied. There are three ways in which glass collapse: by crumbling, by buckling which is most of the times the critical one and the last case is occurred by shear force. Buckling tests should be performed on glass compression members to show visco-elastic buckling behavior. Some formula which produces the correct lower limit and upper limit was considered to check the stability problem of glass columns by Blaauwendraad J. (2007).

A spectacular application of glass supports is presented in the glass roof of the central courtyard of the community administration building in Paris, constructed by

architects J. Brunet and E. Saunier in 1994 **(2.29)**. The 24 m x 24 m roof glazing consists of supporting steel work made of steel profiles holding the roof glazing on spacers. It is carried by cross-shaped 22 cmx 22 cm glass supports consisting of laminated fins with three toughened panes.



Figure 2.29 : Glass column in Administration building in Saint -German-en-Laye, Paris, 1994 (www.architectoid.blogspot.com, 2015).

2.6.3 Glass Shear Walls

Shear walls are formed the fundamental component of the structures lateral force resisting system – acting in bending and shear against in-plane loads such as wind pressure or seismic accelerations (Lenk, 2011). It basically behave like very wide glass columns and it also has buckling risk. It must be careful that load transfer doesn't generate excessive concentrated stresses.

Glass panes are increasingly being used to the stabilization of one storey buildings by acting as shear walls and thus replacing conventional bracings. The behaviour of such structural systems mainly depends on the stiffness of the connections. Huveners (2008) researched a system consisting of a steel frame, a single pane and one of three defined circumferentially glued joint types. It shows that the numerical models are applicable for the purpose of the non-cracking design of glass panes with the bracing a frame as a shear wall.

Furthermore, a number of studies on combining glass with timber and those on the in-plane load bearing capacity of glass panes in *timber-frame wall elements* have been carried out by TU Vienna (Hochhauser, 2011), Linnaeus University (Blyberg, 2011) and as well by ITU. These studies aim at development of new applications of timber-glass elements which could assure certain level of structural resistance and

they research how to increase especially the racking stiffness of the wall elements under a monotonic horizontal point load with using the most appropriate type of the bonding line and the adhesive. As a experimental tests, it will be more discussed in this thesis Chapter 3.



Figure 2.30 : Specimen of timber glass shear wall (Winter, 2010).

2.7 Examples of Glass Structures in Turkey

Glass was used in era of Ottoman Empire as a building material. Glass Kiosk (Camli Kösk) is considerable example of using glass as a building material in cultural heritage buildings of Istanbul **(2.31)**. It is in Dolmabahce Palace's backgarden, view looking northwest. The extensive use of glass provides visual connection of inside and outside. The palace is glittering collection of Baccarat, Bohemian and English crystal as well as Venetian glass, which was used in construction of walls, roofs, banisters, and even a crystal piano (Levine, 2008).



Figure 2.31 : Glass Kiosk (Camli Kösk) in Dolmabahce Palace, 1856 (www.istanbultours.com, 2015)

Furthermore, the ‘Vakko Headquarters’ building project is given as an contemporary example. It was designed by The Turkish architects, REX in Istanbul **(2.32)**. They used the wafer-thin slumped glass for cover the existing old buildings frame. Rather than concealing the building shell, the architects interested in revealing it through the sheets of glass possible. This kind of adaptive reuse brought the forefront of sustainability. The architects turned to the technique known as slumped glass, by which glass is repeatedly heated and cooled until it falls into a mold and assumes the mold’s form. Slumping is typically used to create decorative effects, but REX decided to use it for structural purposes: The glass panels feature an X-shaped impression that gives them vertical and lateral stiffness and strength **(2.33)**. They are also catch light and reflections. The glass units were fixed to the concrete floor slabs with a stainless-steel glazing channel and adjustable brackets and point fixings. (www.arcdaily.com, 2015).



Figure 2.32 : Vakko Headquarters in İstanbul, Turkey (Brake, 2010).



Figure 2.33 : The X-Shaped Glass Panels (Brake, 2010).

Another example, Sapphire Tower, a skyscraper, is the tallest building in Istanbul. It has an overall structural height of 261 meters including its spire. It was designed by Tabanlıoğlu Architects as a high-tech structure that consists of 64 floors **(2.34)**. Sapphire is the first ecological building of Turkey, having two special glass shells,

which can take the outside air naturally, by holes located at every 3 floors. Thanks to this system, the inhabitants of the building are not be affected by the negative weather conditions and external urban noise. These shells are made of two-tiered mesh, aluminum panels, textured and laminated blue and clear glass. (www.wikipedia.com, 2015).



Figure 2.34 : Sapphire Tower (www.bbc.co.uk, 2015).

Tekfen Oz Office building, is the first Leed certified commercial office building in Turkey, designed by Swanke Hayden Connell Architects in 2011. It is the most prestigious project district of the city. The project attained top efficiency mechanically, economically and visually, with the use natural plantations on the floors and facades. The shading provided by plantings and constructive additions on facade will create a comfortable office environment for the inhabitants **(2.35)**. The double-glazed facade of this building combines both low emissivity and solar control properties to minimize heat losses in winter and avoid excessive heat gains in summer. Extra clear glass is also used to ensure a high daylight transmission to let daylight flood into the internal space and thus minimize the need for artificial lighting (Dijkman, 2009).



Figure 2.35 : Tekfen Oz Office Building and its double-glazed façade (www.glassforeurope.com, 2015).

2.8 Adhesives

Adhesive is a nonmetallic substance capable of joining materials (adherents) by surface bonding and the bond possessing adequate internal strength and then the forces transferring from one adherent to the other (Brockmann, 2009). The adhesive bond is developed by a process of adhesion and cohesion. The adhesive has to be applied as a liquid in process of adhesion and then it has to be solid to allow high loads to be carried in its final cohesion stage (McArthur, 2004).

Adhesives are usually used in construction and furniture assembly. The furniture adhesives are light-colored, low-viscosity, and generally do not need much moisture resistance whereas the construction adhesives generally have a high viscosity and need flexibility, but can be dark-colored (Rowell, 2005).

2.8.1 General and mechanical properties of adhesives

Adhesives are polymer materials that consist of simple monomer units recurrently chained to macromolecules. Polymers can be classified according to their thermomechanical properties that are controlled by the molecular structure **(Table 2.4)**.

Requirements on adhesive layer are mainly focused on strength and stiffness. The whole bonded joint has to be rigid enough to provide an optimal structural interaction between joining materials, but on the other hand it has to be flexible enough to redistribute the stress peaks in critical points and enables the full strength of the materials to be utilized (Abeln, 2010).

Table 2.3 : Classification of polymer adhesives (Haldimann, 2008).

Polymer adhesives		
Thermoplastics	Elastomers	Thermosets
Linear or branched chains	Long cross-linked polymer chains	High cross-linked polymer chains
PVB	Silicone (inorganic) Polyurethane (organic)	Acrylic adhesive Polyester resin, Epoxy

Most often used adhesives can be divided according to their modulus of elasticity and shear modulus into flexible-elastic (i.e. silicones, modified silicones and

polyurethanes) and rigid (i.e. epoxy or polyester resin, acrylics). Rigid adhesives have extremely high strength but very low elongation in comparison with elastic adhesives, which show elongation at break even more than 250% (Abeln, 2010). Practical application of different types of polymer adhesives depends on their behaviour under loading, which comes from their material properties or even molecular structure (Netusil, 2010).

Silicones have strength characteristics of a relatively low level but they are extremely resistant to environmental influences (temperature, humidity, UV exposure, etc). According to the product data sheet (Sikasil SG-20, 2009) the tensile strength is approximately 2.2 MPa and the elongation at break 450%. Main silicon adhesives features include wide variety of possible viscosities and good flexibility. As silicones are elastic even at low temperatures and adhere very well to glass and common frame materials, they are extremely suitable for structural glazing systems (Wurm, 2007).

Acrylates show semi elastic behavior with relatively high strength, but lose partly dramatic strength at temperatures above 50°C or high humidity. It is designed to substitute mechanical fastening techniques in structural. According to the product data sheet (SikaFast 5215, 2003) the tensile strength is approximately 10 MPa and the elongation at break 150% . Major features of acrylic adhesives include: Water resistance, durability, flexibility when modified, good low temperature properties, excellent optical properties, low toxicity (Hussey, 1996).

The **polyurethane** adhesive approved for load-carrying timber structures, including glued laminated timber. The performance of the polyurethane adhesive relies to a large extent on the pressure applied during curing. But, both in tension and shear, the strength of polyurethane has less than the strength of the acrylate (Blyberg, 2012).

The other adhesive, **epoxy**, is created by polymerizing a mixture of two starting compounds, the resin and the hardener. Covalent bonds between the epoxide groups of the resin and the amine groups of the hardener (catalyst) that arise from this combination afford for the cross-linkage of the polymer, and thereby it ensures the rigidity and strength of the epoxy. It offers high strength and stiffness but presents brittle failure. The stiffness significantly decrease at high temperature accompanying with large strains (Huveners, 2007). It also presents good adhesion to many surfaces,

a range of mechanical properties depending on formulation and curing, low shrinkage and range of available adhesive forms (such as film, paste one or two component) (Hussey, 1996).

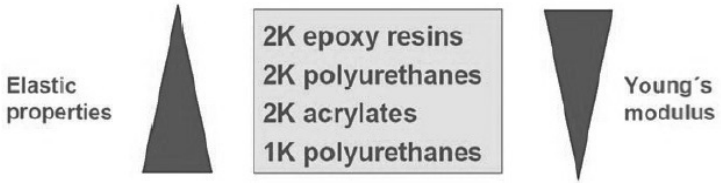


Figure 2.36 : Connection between stiffness and elasticity for common adhesive systems (Abeln, 2010).

A general correlation between elastic properties and young modulus, whereupon a decrease of the young modulus from two component epoxy resins to one component polyurethanes simultaneously goes along with a ductility and deformability increase.

Table 2.4 : General comparison of different adhesive systems (Abeln, 2010).

	Tension and shear strength	Stiffness	Ductility	Viscosity	Temperature resistance	Ageing behaviour	UV resistance	Transparency, colour
Epoxy resin	+ + +	+ + +	+	+ + +	+ +	+ +	+ +	+
Polyurethane	+ +	+ + +	+ +	+ +	+ +	+ +	+ +	+ +
Acrylate	+ +	+ +	+ +	+ +	+ +	+ + +	+ + +	+ + +
Silicone	+	+	+ + +	+	+ + +	+ + +	+ + +	+

Table 2.5 shows that epoxy resin has higher tension and shear strength and stifness properties compare with others. Silicone indicate high temperature and UV resistance. Especially polyurethanes show a wide spectrum of different properties, so that a valuation hard to be made.

The strength of adhesives is dependent upon a number of factors: environment (chemical, UV, moisture), temperature and thermal behaviour of elements, rate and duration of load, surface rougness, joint dimensions and curing (The Institution, 1999). It is also dependent on the type of solvent and the bond tickness (McArthur, 2004). Each adhesive shows different behaviour under increasing load regarding to the thickness of the joint. It was proved experimentally for common types of adhesives, that by increasing thickness of the joint over the ideal value, possible

elongation of the adhesive layer increases too, but the connection loses its load carrying capacity (Netusil, 2010). Furthermore, the fundamental requirements for all adhesives are permanence, durability and compatibility with other building materials (Winter, 2010).

The difference of two- component and one-component adhesives; Two- component adhesives or adhesives with booster system should be used for such a kind of connection, where the width of the connection is to big (over 30 mm) for humidity curing. One-component adhesives (mainly polyurethanes), which are cured by air humidity, cannot harden for depths wider than 15 mm in a reasonable period of time. The two- component provides uniform hardening of the adhesive layer, process of curing doesn't depend on air humidity and the whole curing is finished in hours and not in days as for one component adhesives (Abeln, 2010).

2.8.2 Adhesives for timber glass composites

In the scope of experiments that take place in the third chapter of the thesis, adhesive is used to bring together timber glass materials. Adhesives used with timber and glass composite building materials are analyzed in this chapter.

The bonding timber glass composite is an issue of research since the early 1990's. Thus, the glass can be usable for structural timber construction as a load-bearing element. The main characteristic of timber glass composite system is that timber provides ductility and glass offers resistance and stiffness. These characteristics do not cancel themselves out. Instead, they are combined in a balanced behaviour. Therefore, if the adhesive is not able to minimally absorb the various resulting stresses, it will not efficiently play the role of interface, as it will not prevent from a direct confrontation of different behaviours of materials. The adhesive must allow bending, expansion and shrinkage of timber, according to loading and humidity variations. Given the basic difference of characteristics between glass (brittle) and timber (ductile), it is believe that this could be the best way of enhancing the performance of the different composing elements in a unitary set.

Structural adhesive bonding is preferable to combining timber glass composites due to five main reasons: (Cruz, 2008)

- Ideal balance between strength and ductility, combining different materials

- Uniform distribution of forces
- Reduction of materials fragilization by avoiding drilling
- Prevention of high peak stresses on glass surface

The elastic adhesive bond represents an entirely new technology compared to the rigid adhesive bond in usual timber constructions. They have the ability to transmit loads from timber to glass in a uniform manner and linear stress initiation, so that glass can be activated as structural element. It is also of great importance that the adhesive brings together strength and flexibility.

Today primarily silicones, silanes, polyurethanes or acrylates with different properties (curing mechanism, mechanical behaviour, ageing resistance, application behaviour, etc.) are used as adhesives for timber glass composites.

Cruz (2008) tested different type adhesives such as silicones, methacrylates, polyurethane, epoxy, acrylic, superflexpolymers and MS polymers regarding shear stress, temperature and water saturation tests. As a result, the superflexpolymers adhesive is reported to have the best balance between strength and ductility. It is shown that the load capacity of polyurethane adhesive for some specimens is as high as the polymer adhesive and the load capacity of acrylic adhesive is the more than others.

In Blyberg (2012) study, three different adhesives, silicone, acrylate and polyurethane, intended for adhesive joints in structural timber/glass applications are presented. Of the tested adhesives, the acrylate (SikaFast 5215) provided the largest strength, both in tension and shear. The strength of the polyurethane had a large alteration indicating that this type of bond was more sensitive to disturbances than the other two. The acrylate adhesive would be the most appropriate adhesive for its high strength property but the stiffness could be reduced due to termal alteration.

Pequeno (2007) focused on the analysis of shear stress tests on adhesive types such as silicone, superflex polymers, methacrylate and acrylic tape. These tests indicated the existence of three different groups: adhesives highly resistant and insufficiently flexible in this context – methacrylate (and also two-component acrylic adhesive); highly flexible adhesives, yet insufficiently resistant to the loading they could be subject to in real situations – silicone and acrylic tape – and, finally, adhesives that

balance both key factors in this research: strength and flexibility – this being the case of superflex polymers.

In Niedermaier (2012) study the characteristic behaviour of gluing (silicone and polyurethane adhesives) for structural sealant glazing was evaluated during exposure to tension load up to a stress level of approx. 30% of the ultimate strength and different temperatures for a duration of 5000 hours. Silicone adhesive exposed to tensile stresses during different temperature loads and it showed that different loads of temperature only insignificantly influence the level of ultimate strength and no temperature-dependent embrittlement of the adhesive in the elastic area. It can withstand the most different climatic influences.

2.8.3 Silicone for timber glass composites

In the scope of experiments, silicone is used as adhesive to bring together timber and glass materials. Therefore, silicone adhesive is mentioned in a more detail in this chapter.

Regarding the analysed adhesives, silicone is the most advisable for timber glass composites, as it allows greater indexes of flexibility, thus assuring the needed structural mechanical resistance and load distribution ability (Cruz, 2008). It is chosen not only for functional and structural reasons (UV resistance), but also for aesthetic reasons. Due to the strength of the Si-O bond, silicone can stand high temperature without decomposing; hence it can be used as a fire retardant.

In Larsson (2008) study, the simulations of the large-scale tests revealed that the silicones were generally stronger than the stiffer adhesives when applied to a joint of larger geometry. This is explained by the fact that the softer silicones has a higher capacity of strain that evens out the stresses and thus avoid the stress-concentrations that build up in the stiffer adhesives.

The study in modern shell structures Wellershoff (2006) applied acrylates, polyurethanes and silicones, with glass being laminated and heat-strengthened. Wellershoff came to a conclusion that the shear stiffness of polyurethanes and acrylates was higher than that of silicone. On the other hand, with the increase of temperature the shear stiffness of polyurethanes and acrylates decreased while the stiffness of the silicone remained unaltered.

The decisive parameter for the silicone bonds is the bond thickness. Therefore, the fixture was used to obtain a pre-defined bond line thickness rather than obtaining a certain pressure during gluing. The nominal bond line thickness was 4 mm for the silicone. Furthermore the silicone adhesive tends to fail mainly in a mixture of adhesion to timber and cohesion in adhesive, but in Blyberg (2012) shear tests some more specimens fail partly in adhesion to glass.

2.8.4 Standarts of Adhesives

Standarts relevant to adhesives can be cited as following;

BS EN 302-1:2004 ‘Adhesives for load-bearing timber structures: test methods. Determination of bond strength in longitudinal tensile shear strength’ specifies a method of determining the shear strength of adhesive bonds. It is applicable to adhesives used in load-bearing timber structures.

BS EN 302-2:2004 ‘Adhesives for load-bearing timber structures: test methods. Determination of resistance to delamination’ describes a method for determining the resistance to delamination of bonded joints.

ASTM D907 ‘Standard Terminology of Adhesives’ standard is a compilation of definitions used in the science and technology of the adhesives industry.

ASTM D906 ‘Standard Test Method for Strength Properties of Adhesives in Plywood Type Construction in Shear by Tension Loading’ covers the determination of the comparative shear strengths of adhesives in plywood-type construction.

ISO 14615:1997 ‘Adhesives- Durability of structural adhesive joints- Exposure to humidity and temperature under load’ describes the equipment and the test procedure used to evaluate the durability of adhesive-bonded joints exposed simultaneously to heat, humidity and load.

ISO 19212 ‘Adhesives - Determination of temperature dependence of shear strength’ specifies methods for determining the temperature dependence of the shear strength of the adhesive or adhesive bond in adhesively bonded products.

Moreover, according to the standarts, type of tests (tension ,shear and torsional tests) for obtain some values like tension strenght, strain, young modulus and shear strength are given in **Table 2.5**

Table 2.5 : Suitable tests for obtaining mechanical values (Abeln, 2010).

Type of test	Standards	Obtained values
Tension test of substance specimen	EN ISO 527 – Determination of tensile properties	Tension strength and strain, Young´s modulus, Poisson´s ratio
Block shear test	EN ISO 13445 - Determination of shear strength of adhesive bonds between rigid substrates by the block shear method	Shear strength and strain, shear modulus
Single lap shear test (SLS) of thin adherents	EN 1465 - Determination of tensile lap-shear strength of bonded assemblies	Shear strength
Single lap shear test (SLS) of thick adherents	EN 14869-2 - Determination of shear behaviour of structural bonds	Shear strength and strain, shear modulus
Torsional test of butt-bonded hollow cylinders	EN 14869-1 - Determination of shear behaviour of structural bonds	Shear strength and strain, modulus, combined tension-shear loading
Dynamic mechanical analysis (DMA)	EN ISO 6721 - Determination of dynamic mechanical properties	Glass transition temperature

2.9 Timber Glass Composites

Nowadays, the use of timber is increasing in contemporary housing. It is a preferable building material due to its low self-weight and high strength, hence making it especially suitable for seismically active areas. It is also an ideal construction material from the perspective of environmental impact and energy efficiency as it has very low heat transmission, stores carbon dioxide and needs very little energy for processing (Ber, 2013). In consideration of the influence of the timber based construction system on other trades (reduction in construction time, possibly saving foundation, cleaner worksite, work in wintertime, electricity) overall costs can be reduced. In addition, by calculating useable areas at same gross are the cost over-runs can be reduced to 5% (Winter, 2012).

In addition to this, modern architecture demands more transparent building elements. Natural lighting is one of the most important factors in our lives. The basic problem of glass is its unpredictable and brittle failure behaviour due to the week in tension. The main idea was to connect these two materials together to provide the best properties of the composite. The main characteristic of this composite system is that timber provides ductility and glass offers resistance and stiffness. Glass and timber are bonded by adhesives to form composite structural elements. Bonding with an appropriate adhesive could provide a sufficiently uniform stress distribution at the transition between the materials (Zlatinek, 2014).

Glass is used in this composite structure for the three Vitruvian reasons: Aesthetics (venustas) – architectural expressivity, transparency, magic and illusion and natural lighting; functional (utilitas) – thermal efficiency, sustainability and timber protection; structural (firmitas) – structural capacity, stiffness, strength and new field not explored architecturally (Cruz, 2008). First of all, it will allow benefiting from natural lighting in a way not much explored so far, creating light paths and improving spatial perceptions.

The considerations show that timber-glass load bearing system represent a very efficient alternative to classical stiffening systems for timber constructions. The comparison of different parameter influences represent that timber-glass load bearing system could be adapted in different ways to the requirements of a timber construction. The materials of the system which can be applied horizontally, as a slab, and vertically, as a resistant wall, is multi-structurality. It integrates passive solar systems and bioclimatic functions, which result in energetic efficiency, and constitutes a sheer innovation in the field of sustainable prefabricated structural elements (Pequeno, 2009).

It is an important advantage of glass-timber composites that manufacturing of these structural elements doesn`t demand heavy industrial facilities. On the contrary, these composite elements are produced by fast and low power consuming techniques. Prefabricated elements in timber engineering have many advantages over traditional types of construction. Traditional approaches to construction are expensive to design and implement, slow and complicated. The suitability of glass-timber composites to ecological structures also empowers the value of these systems.

Timber-glass hybrid elements meet modern architecture´s demands and can help increase the use of timber as building material. Timber-glass composites have a lot of potential to be discovered. The advantages of using timber-glass composite structures, concerning constructive aspects and structural behavior, are:

• The timber-glass composite elements which are multifunctional as load bearing and stiffening and as façade elements are advantageous for ecological and economical reasons,

• Industrial prefabrication and applicability of load-bearing structure,

• Near waste-free building design,

• Architecture and modulation. Metrics, modularity, habitability and urbanity;

• Recyclability of all building components after service life,

• Lighting and shadowing. Architectural expressiveness and effective solar protection in several orientations,

• Energy-saving (Thermal, acoustic, lighting efficiency), sustainability and environmental-friendly constructions (Winter, 2012).

Besides these advantages, combining timber and glass to get an appropriate load-bearing element is also a challenging process. Unfortunately, the coefficients of thermal linear expansion (αt) of timber and glass are quite different (almost a factor of two in the grain direction). Temperature differences can cause high shear stresses in the adhesive between the timber frame and the glass panels (Ber, 2013).

There are numerous parameters, which influence the horizontal resistance and stiffness of the timber-glass wall elements, i.e. material properties and thickness of glass panes. The connection between timber and glass has a significant influence.

2.10 Examples of Timber Glass Composites in Turkey

In the structures where glass and timber are used together in our country, glass generally takes part as facade material and timber-glass composite structure component is not used as load bearing. Ertaş and Bakırcılar bazaars, which are located in Bursa for about 120 years, have recently insulated with a glass covering **(2.37)**. Laminated timber beams with the total length of 4000 meter and the dimensions of 15x40 cm are used and placed with tempered glasses with the thickness of 16 mm.



Figure 2.37 : Roof Construction of Ertaş and Bakırcılar bazaars, Bursa (Archive of Doğaç Toy).

The second example of timber glass composites usage is Çanakkale Seramik Headquarters. Two different buildings which planned as winter garden form for showroom and café purpose, projected by Erginoğlu& Çalışlar Architecture. Structural laminated timber beams were used in this winter garden. It's a modern project in which glass and timber used together, offers the warmth of timber and transparency of glass (www.asmaz.com, 2015).



Figure 2.38 : Çanakkale Seramik Headquarters (www.asmaz.com, 2015).



Figure 2.39 : Laminated timber beams of building (www.asmaz.com, 2015).

Futher example, a swimming pool is covered with timber beams and glass, designed by Architect Vedat Tokyay in his bureau in Antalya. The roof has a simple and lightweight construction, thus the place under it has a very natural atmosphere **(2.40)**.



Figure 2.40 : A swimming pool, Vedat Tokyay - Oran Architecture (Archive of Vedat Tokyay).

In two buildings he designed, Architect Şevki Pekin has used timber and glass through a simplicity that intends to indispose nothing in nature **(2.41)**. These buildings have an effect as a transparent box in nature.



Figure 2.41 : Summer house, Dikili, 2002 (Archive of Şevki Pekin).

The last example of timber glass composites is Dardanel Administration Building. Timber house of the 19th century was converted into a new office for Turkish tinned tuna company administration building by Alatas Architecture & Consulting in Istanbul. **(2.42)**. The original windows of building are so small and for this reason, the interior parts of the building are completely dark. Alatas Architecture focused to find some solutions to create lighter spaces. So the success of the project is getting enough daylight to inside of building.



Figure 2.42 : Dardanel Administration Building (www.dezeen.com, 2015).

Alatas Architecture & Consulting decided to preserve the old timber door and then added the second set of glass doors to entrance to allow light into the building while keeping the elements out. Thanks to this historical timber door is always open, it can be connect outside with the interior **(2.43)**.



Figure 2.43 : Second set of glass doors and glass-roofed of building (www.dezeen.com, 2015).

The backside of the building was altered with the addition of floor-to-ceiling windows and a glass-roofed extension. There is the main meeting room. Glass panels in the floor of this room allow daylight to pass into the below server room. The architects also added a completely new spiral staircase and elevator shaft made of glass through the middle of the building, which dissipates light from a skylight above it **(2.44)**, (www.dezeen.com, 2015).

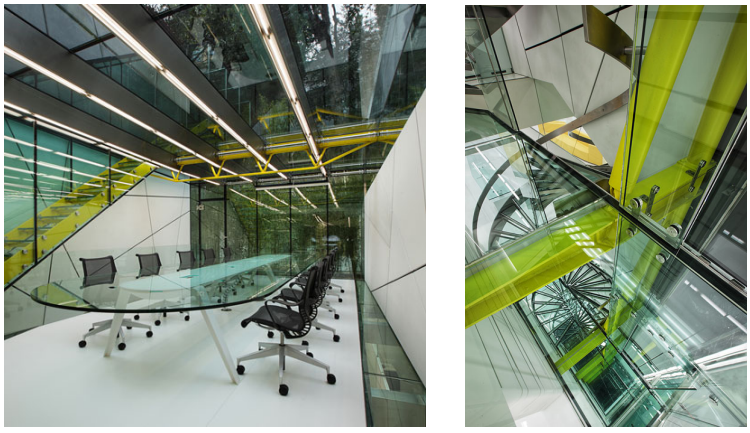


Figure 2.44 : Floor-to-ceiling windows of meeting room, staircase and elevator (www.dezeen.com, 2015).

3. EXPERIMENTAL TESTS

3.1 Previous Experiments Under Seismic Loads

This section summarizes previous experimental studies aimed for developing a better understanding of the behaviour of glass and timber under seismic loading conditions. Early experimental studies by Lim and King (1991) evaluated the experimental racking tests of curtain wall glazing systems. The parameters studied included displacement rates, boundary conditions (building deformation characteristics and two specimen configurations), number of cycles at each amplitude and different incremental cyclic displacement. The result indicated that the rate of displacement is the main parameter affecting the behaviour of systems tested. Besides, the glazing systems tests indicated that in general, they would perform well under an earthquake attack when installed upon buildings designed to current code requirements. In addition, the stiffness of curtain wall glazing systems was evaluated. Unless a glazing system is actively separated from the structure, its stiffness in relation to the structure interstrorey stiffness may be significant, particularly in the initial stage of loading.

In Yasumura (1997) study, the methods to estimate the static and dynamic performance of timber-framed shear walls were investigated by comparing the simulation by non-linear and equivalent linear earthquake response analysis with the experimental results of pseudo-dynamic tests. Specimens had timber frames of 1.82m or 2.73m length and 2.44m height sheathed with 9.5mm thick spruce plywood on one side as shown in Figure **3.1**. Four plywood sheets were sheathed horizontally. No blocking was applied to the joints between upper and lower plywood sheets except for the one specimen. In the seven specimens, two plywood sheets were sheathed vertically on the frame. In six of the seven specimens had an opening (window or door) and had hold-down bolts at the both ends of shear walls connecting studs to steel foundation with the screws except the two specimens. In these

specimens, hold-down bolts were not attached to the studs besides the opening. The monotonic and reversed cyclic loads were applied at the end of the girder by the computer-controlled actuator, horizontal and vertical displacements of wall were measured by electronic transducers.

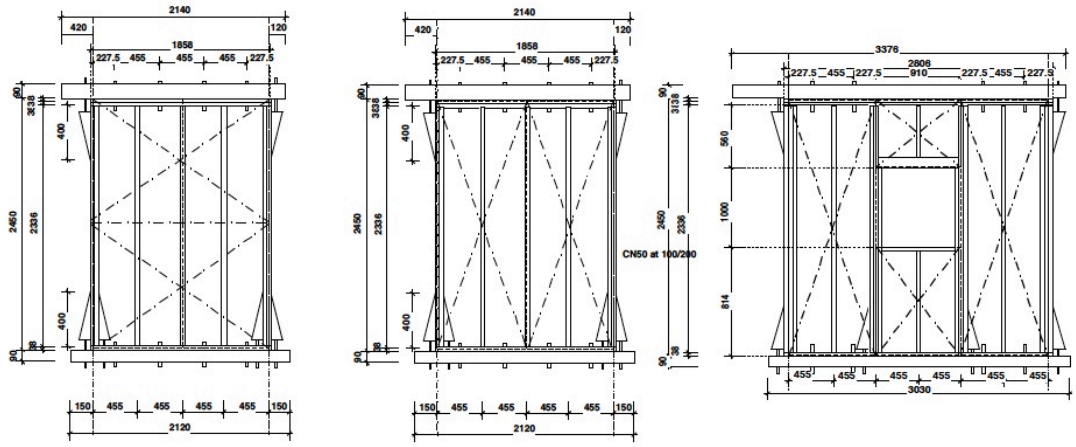


Figure 3.1 : Shematic diagram of specimens (Yasumura, 1997).

The yield load, yield displacement, maximum load, maximum displacement, ultimate load and ultimate displacement obtained from the experiments. Experimental results showed that the blocking plays an important roll to transmit the shear forces between horizontally applied plywood sheets. The yield and ultimate loads of the specimen with blocking were approximately 1.5 times higher than those of without blocking. Thus, the shear strength of shear walls with horizontal sheet application without blocking is not proportional to the nail spacing, and shows more complicated mechanical properties than those with blocking. Significant bending of studs was observed in the shear wall without blocking, while those remains almost straight in the shear wall with blocking. The results also showed that there is a considerable decrease of strength by omitting hold-down bolts at the end of opening especially in the case of those with door opening, and some reduction of the shear strength is necessary to omit the hold-down connecting studs at the end of opening.

In Tokyo, Foliente (2000) researched the reliability assesstment of timber shear walls under earthquake loads. A modified version of the BRANZ procedure for lateral capacity rating of bracing walls was used to determine the sustainable lateral mass of a 910-mm wide ‘2x4’ timber shear wall. 910 x 2450 mm shear wall was choosen that was typically found in Japanese houses and was commonly regarded as the minimum size shear wall in Japan. This wall was sheathed with 9.5-mm thick conifer plywood

on one side. Then lateral load was applied to the top of the wall following the static cylic protocol **(3.2)**. This system model is capable of producing various hysteresis shapes, and exhibits strength and stiffness degradation and pinching.

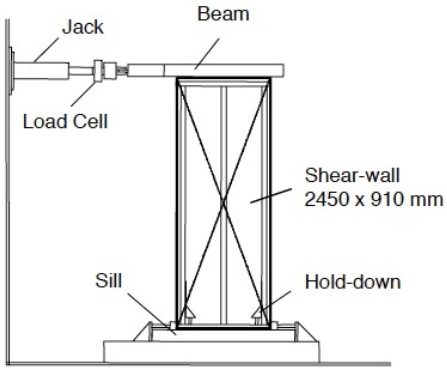


Figure 3.2 : Static-cyclic test setup (Foliente, 2000).

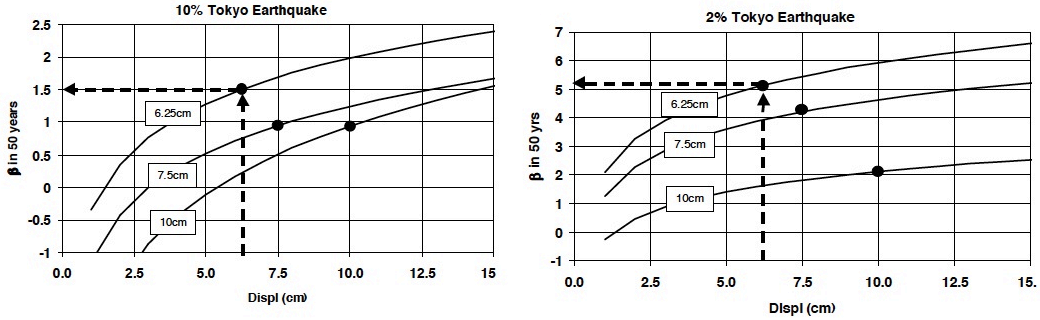


Figure 3.3 : Reliability curves for the shear wall with sustainable mass obtained from Tokyo earthquake records with: 10% and 2% probability of exceedance in 50 years (Foliente, 2000).

Figure 3.3 can be used to determine the implied reliability of the shear walls rated using the modified BRANZ procedure for various values of displacement capacity and earthquake level. The reliability index is obtained by determining the intersection of the reliability curve for a given displacement capacity and a vertical line at the same displacement value in the abscissa.

In conclusion, they found that the reliability index β ranged from 0.94 to 5.20, depending on the assumed displacement capacity determined from the static cyclic test, and the intensity of earthquakes used to generate the displacement spectrum. The choice of dependable displacement capacity and design earthquake level can significantly affect the predicted reliability of the wall.

Hacker and Ansell (2001) investigated property changes and fatigue damage accumulation of timber-epoxy laminates under constant amplitude fatigue tests in tension-tension (R = 0.1), compression-compression (R = 10) and reverse loading (R= -1). They found that the reverse loading is the most severe mode of cyclic loading. In terms of static strengths, the wood laminate is weaker in compression than in tension. However at low levels of stress, following many fatigue cycles, the fatigue life is greater in compression-compression than in tension-tension. Maximum and minimum fatigue strains were monitored during the fatigue tests. In tension-tension, the strains remained constant through the test, but they increase significantly close to failure. The sudden increases of strains were found to correspond to the initiation and growth of fatigue cracks along the timber grain, as each crack initiation causes a small step in strain. The property changes can be detected throughout fatigue tests. Normalisation of fatigue data demonstrates that the fatigue behaviour of timber-epoxy laminates is consistent.

Behr's (2001) laboratory studies were conducted to investigate the cracking resistance and fallout resistance of different types of architectural glass installed in the same storefront and mid-rise wall systems. Effects of glass surface prestress, lamination, wall system type, and dry versus structural silicone glazing were discussed. Rectangular steel tubes at the top and bottom of the facility were supported on roller assemblies, which permit only horizontal motion of the tubes. The bottom steel tube was driven by a computer-controlled hydraulic ram, while the top tube was attached to the bottom tube by means of a fulcrum and pivot arm assembly **(3.4)**.

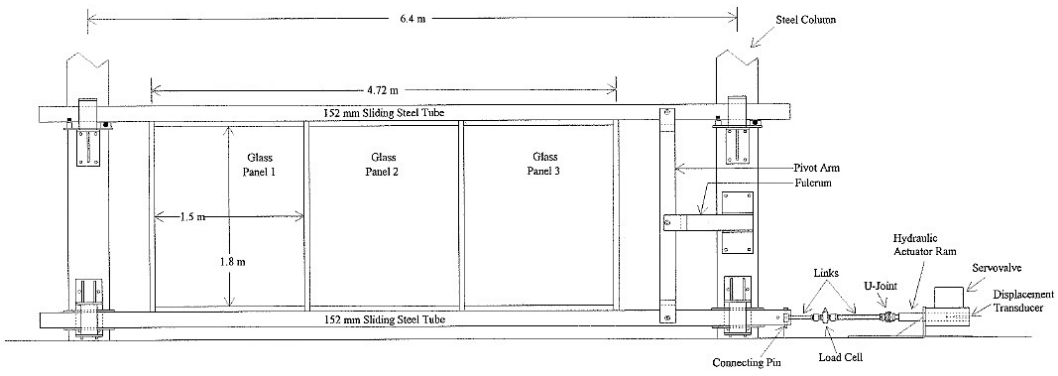


Figure 3.4 : Sketch of the dynamic racking test setup (Behr , 2001).

The test facility accommodated up to three glass test panels, each 1.5 m wide x 1.8 m hight. Several types of architectural glass were tested under simulated seismic conditions in the storefront and mid-rise dynamic racking tests.

Glass failure patterns were recorded during each storefront and mid-rise test. Annealed monolithic glass tended to fracture into sizeable shards, which then fell from the curtain wall frame. Heat strengthened monolithic glass generally broke into smaller shards than annealed monolithic glass, with the average shard size being inversely proportional to the magnitude of surface compressive prestress in the glass. Fully tempered monolithic glass shattered into much smaller, cube-shaped fragments. Annealed monolithic glass with unanchored 0.1 mm plastic PET film also fractured into large shards, much like annealed monolithic glass without film, but the shards adhered to the film.

Dynamic racking tests showed that annealed and heat-strengthened laminated glass exhibited higher resistance to glass fallout than monolithic glass. Glazing details were also found to have significant effects on the seismic performance of architectural glass. Specifically, architectural glass within a wall system using a structural silicone glaze on two sides exhibited higher seismic resistance than did identical glass specimens dry-glazed on all four sides within a comparable wall framing system. From the dual perspectives of protecting life safety and maintaining building envelope integrity and serviceability, annealed or heat-strengthened laminated glass units were advised for retrofit building envelope systems.

Tongji University in China (Kang , 2004) investigated the effects of upper storeys and vertical loads on the performance of the LFWC (light-framed timber construction). Nine full-scale light-framed timber construction specimens were tested under cyclic load referring to the ISO 16670 (Timber structures-Joints made with mechanical fasteners- Quasi-static reversed-cyclic test method test protocol). The specimens were identified with the number of the storey or the openings in each shear walls **(3.5)**. A steel frame was used to transfer the pull and push action from the two hydraulic actuators to the test specimen. This steel frame was hanged at the elevation corresponding to the middle of first floor diaphragm via cables tied on the gantry frames **(3.6)**. The cyclic load was applied at a rate of 20mm/s. Each phase included three cycles, except for the five initial phases of single cycle.

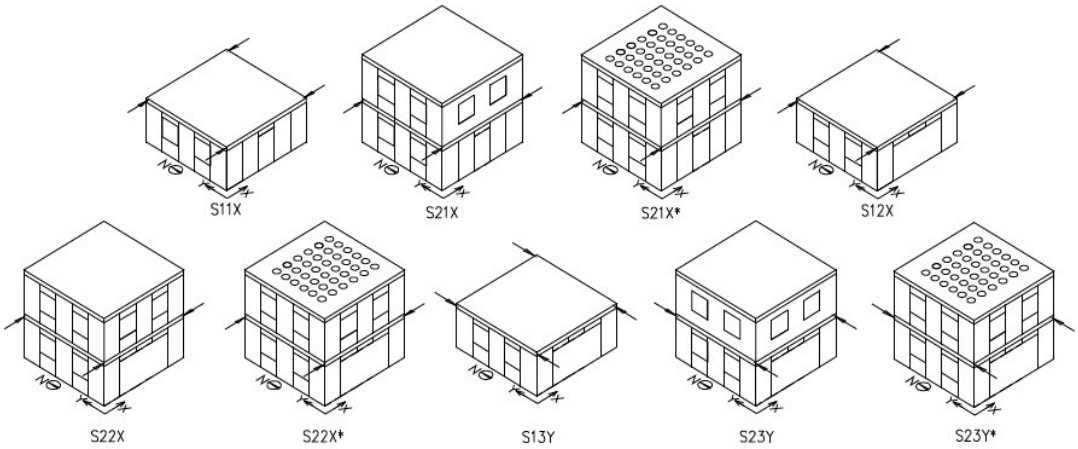


Figure 3.5 : Sketch of the test specimens (Kang , 2004).

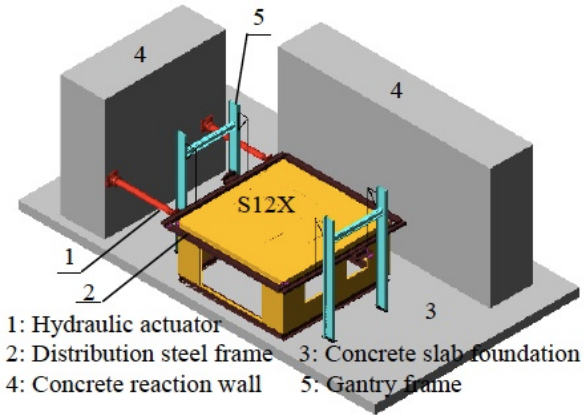


Figure 3.6 : Sketch for general arrangement of test setup (Kang , 2004).

According the conclusions of the experiment, the upper storeys or the vertical load can improve the elastic stiffness and reduce the ultimate and yield deflection of the timber framed shear walls, meanwhile they also can make the timber framed shear walls in the lower storeys brittle and destructed prematurely. The upper storeys or the vertical load had little effect on the lateral load capacity of the timber framed shear wall in the lower storeys.

Another study, Ayoup (2006) proposed a new model for nonlinear seismic analysis of timber building structures. The timber shear wall was modeled by using a Single Degree of Freedom (SDOF) system with calibrated parameters. The SDOF system with degrading pinched hysteretic behavior was proposed for evaluating global behaviors. Four types of degradation were simulated: strength degradation, unloading stiffness degradation, accelerated stiffness degradation, and cap degradation.

The goal of this work was to develop a numerical model that captures as accurately as possible the nonlinear cyclic behavior of timber structures, including all types of degradation. So that this degrading behavior was observed during experimental testing under quasi-static cyclic loading. The finite element model consisted of an elastic shell element to model the plywood shear wall, elastic beam elements to model the studs and top and bottom plates, and distributed interface elements to model the nails. The study confirmed the accuracy of the methodology and the importance of incorporating degradation effects for global evaluation of the behavior of timber structures.

Memari (2011) presented a study in which four-sided structural sealant glazing (SSG) insulating glass curtain wall units were subjected to cyclic racking test methods in accordance with AAMA 501.6 "Recommended Dynamic Test Method for Determining the Seismic Drift Causing Glass Fallout from a Wall System." The study evaluated acceptable sealant stress levels for seismic design and the durability of silicone used in the SSG system as compared to dry-glazed systems based on glass performance. Three full-scale identical curtain wall mock-ups, including the corner section (three face units and one corner unit) were fabricated **(3.7)**. The structural sealant bead along the vertical mullion has a glue line thickness of 14mm and a width of 14 mm whereas along the horizontal mullion has a glue line thiss of 8mm and a width of 14 mm. The racking testing showed that the sealants can cycle up and down (in tension) to 50 psi (345 kPa) without adversely affecting the ultimate properties of the sealant. Silicones provide the strength and flexibility to withstand significant seismic-induced movement. Silicone also offers a flexible anchoring method when used on all four sides and, through curtain wall system racking testing, it has been shown to perform satisfactorily at high racking displacement, with acceptable damage levels that leaves the system still operable.

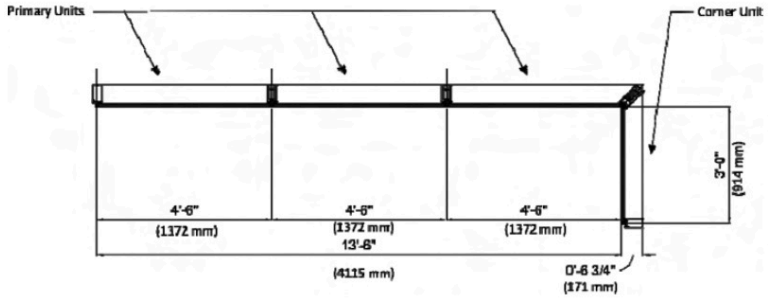


Figure 3.7 : The plan of curtain wall model (Memari , 2011).

In Japan, Okabe (2012) researched effect of vertical load based on ISO21581 (specifies the static and cyclic lateral load test for shear wall) under cyclic lateral load test of Sugi CLT (Cross Laminated Timber). Sugi is most popular softwood in Japan. Basic dimension of Sugi CLT wall panel was 1000mm width, 3000mm height and 90mm thickness. Three types of CLT shear wall were setting up and test of wall is named according the number of panel, 1P, 2P and 3P. Wall to wall connection is 150mm width and 27mm thickness LVL spline attached and screwed. Appling lateral load on test shear wall was used actuator loading jack and vertical load on test shear wall was used oil jack with feedback controlled using load cell arranged on the top of shear wall **(3.8)**.

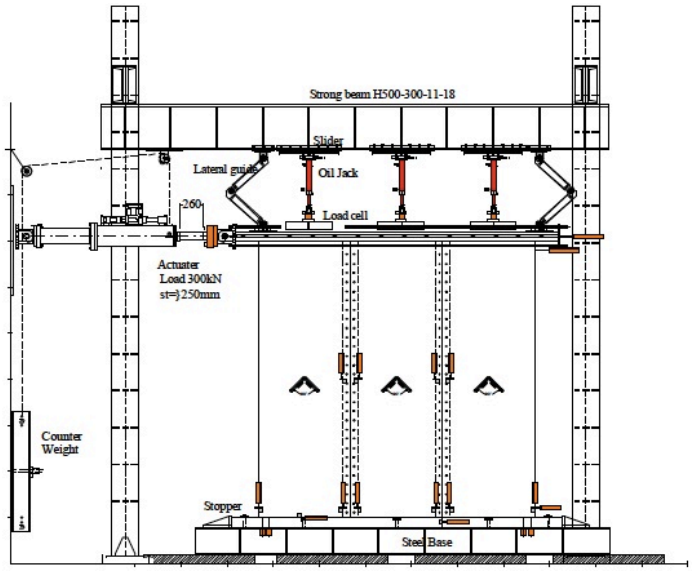


Figure 3.8 : Test Configuration of 3P of CLT wall panel (Okabe , 2012).

Load-Displacement curve of 1P CLT shows over 30kN strength and high ductility. Ductility of test results of 2P and 3P is reduced because LVL spline of wall to wall connection is failed splitting. On the basis of the experimental data obtained from cyclic loading test of shear walls indicated that main deformation mode of Sugi CLT shear wall was shown rocking mode (Okabe, 2012).

Along the “Load Bearing Timber Glass Composites (LBTGC) project”, number of studies on combining glass with timber and those on the in-plane load-bearing capacity of glass panes in timber-frame wall elements have been so far carried out by Holzforschung Austria (Neubauer, 2008) and the Technical University of Vienna, Hochhauser (2011a) and Hochhauser (2011b). In the experimental analysis birch plywood, 8 mm thick/1250/2500 mm float glass and two-component silicone and

epoxy resin and acrylic were used. Epoxy resin was used at all corner for forming block area, so the setting blocks only able to transfer compressive forces. The elements were tested with the horizontal point load acting at the top of the wall and supported by two supports, the tensile and the compressive **(3.9)**.

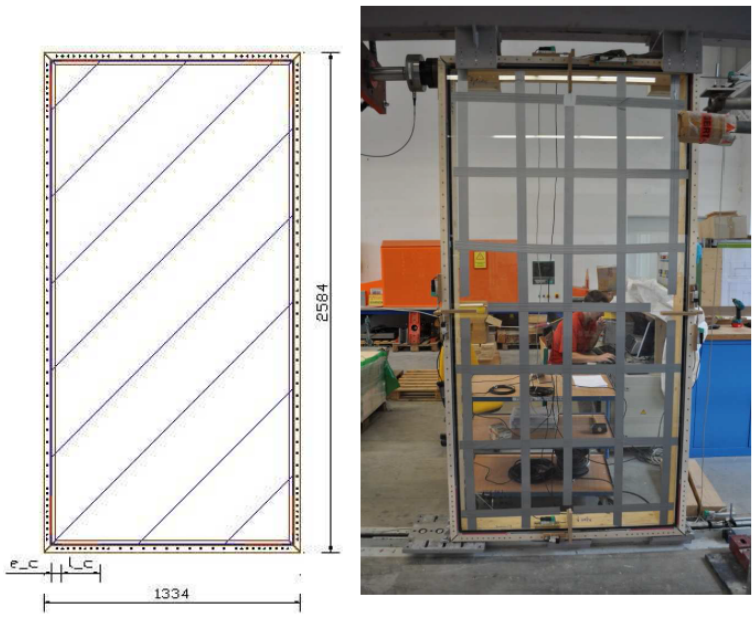


Figure 3.9 : The test samples were subjected to the horizontal point load at the top edge (Hochhauser, 2011b).

The high stress of the compression diagonal has naturally led to a high loading of the connection means in the block area, which eventually led to a lateral tension fail in the timber substructure. Then the setting blocks led to a sudden load transfer on the shear bond, which then abruptly failed cohesively **(3.10)**.



Figure 3.10 : Cohesive failure in the silicone (Hochhauser, 2011b).

For the first sample an expected failure load of Fmax = 50 kN was elected. But due to cohesive failure, horizontal force F=17.2 kN was occurred **(3.11)**.

A simple transversal reinforcement try with timber body substructure was arranged for the second specimen and the expected ultimate load Fmax est, reduced to 20 kN **(3.12)**.

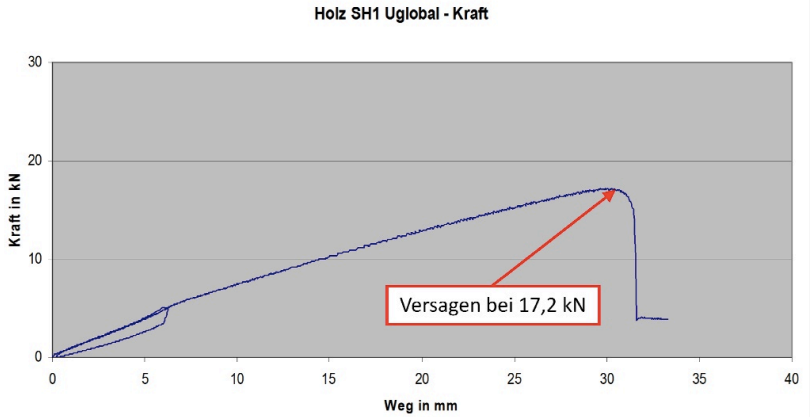


Figure 3.11 : Force-deformation diagram for the first specimen (Hochhauser, 2011b).

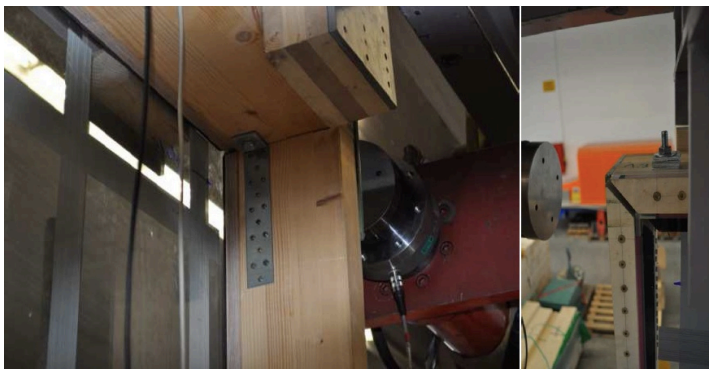


Figure 3.12 : The simple transverse reinforcement for the second specimen (Hochhauser, 2011b).

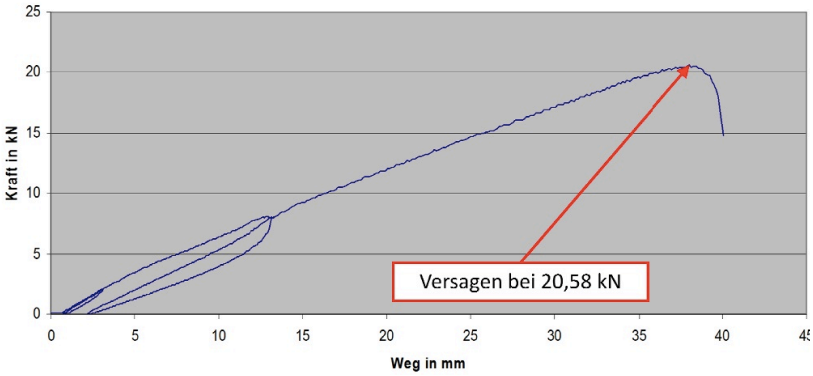


Figure 3.13 : Force-deformation diagram for the second specimen (Hochhauser, 2011b).

A horizontal force load F=20.58 kN was occurred for the second specimen **(3.13)**. By placing a simple transverse shear reinforcement, the horizontal load was increased by 20%. But failed at the second attempt in the substructure, a steel frame

as the new test confirugation was arranged. Firstly an articulated steel frame was made for the high performance disks with steely substructure, which was designed for a maximum head displacement of 40 cm **(3.14)**.

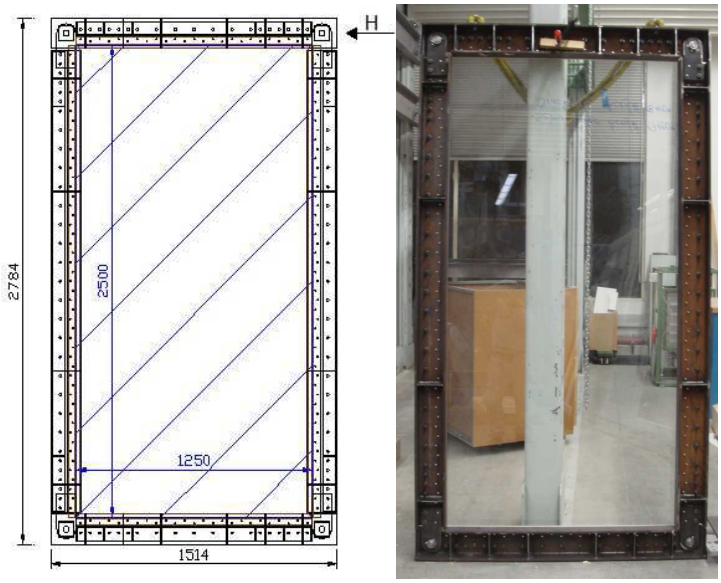


Figure 3.14 : Graphical representation and photograph of the steel test frame (Hochhauser, 2011b).

During the experiment, the buckling of the float glass led to a sudden deformation out of the plane. The glass was broken due to excessive compressive stress. Force-deformation diagram for the test of the specimen is given **(3.15)**.

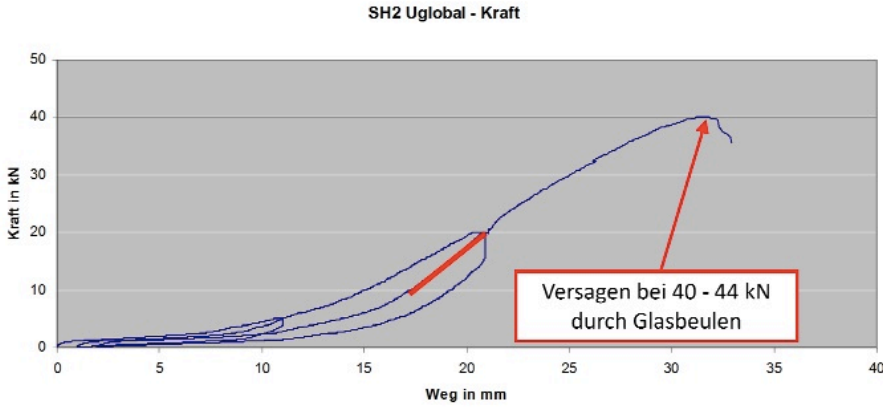


Figure 3.15 : Force-deformation diagram for the third specimen (Hochhauser, 2011b).

In force-deformation diagram, a breaking load of 40 kN for the third specimen can be seen (Hochhauser, 2011b). Furthermore, a two-component acrylic adhesive was used with this experimental configuration (with steel frame) , it has a large shear modulus and breaking load of about 74 kN.

Along the “Load Bearing Timber Glass Composites (LBTGC) project”, participants from Slovenia (Ber, 2013a) tested the shear wall elements composed of timber frame and glass panes under the horizontal monotonic point load as well as the horizontal cyclic point load. The aim of the study is to determine the racking resistance and stiffness of the timber-glass wall elements considering various types of the bonding line conditions (blocking, semi-blocking and non-blocking system) and different types of the adhesives (elastic, semi-rigid and rigid).

When monotonic, predictive static loads acting on wall elements, the most important is to achieve a high static resistance and stiffness whereas cyclic and dynamic (seismic) loads acting on wall elements, a high ductility is the most important fact have to be achieved. As a sample, the single fully-tempered (toughened) glass pane (10mm) placed in the middle plane of the timber frame (dimensions of 1250/2640 mm) is adhesively bonded to the timber frame. Adhesives used for a linear joint between the timber frame and glass are two-component silicone, one-component polyurethane and two-component epoxy. The test specimens were exposed by the vertical piston to the force F, approximates the lateral load, ranging from point 0 to the failure point **3.16.** By all the test groups the maximal vertical displacements (w) under the acting force and slips in the tensile and compression zone of the plane were measured.

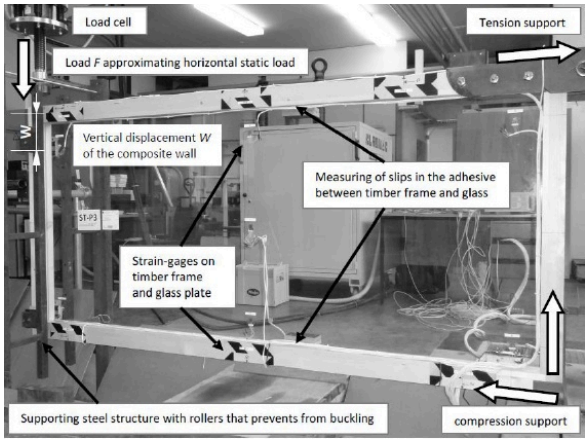


Figure 3.16 : Test Configuration (Ber, 2013a).

The result indicated that silicone and polyurethane test samples both with end-joint type 1 (the adhesive is placed in the lateral surface of the glass-timber connection) demonstrate similarity in terms of maximal vertical displacement under the force. The failure modes of the elements with elastic adhesives (silicone and polyurethane)

demonstrated a relatively ductile failure with destruction of the corner connection between the timber elements while the failure of the test samples with a very stiff adhesive (epoxy) was completely brittle with a glass rupture in the compressive diagonal. After the failure modes of the elements with elastic adhesives as timber corner destruction, (Ber, 2013a) tested to strength the timber corner with steel connecting elements. By comparing the results, it is evident that the force of the corner destruction was significantly improved, from 13.43 kN to 16.38 kN respectively. Additionally, the stiffness was improved in a very high range.

Slovenia also tested (Ber, 2014) some specimens subjected to the combination of the horizontal point load and the constant uniform vertical load. For this purpose, two different types of the test samples were tested in a sense to investigate the influence of the number of the bonding line connections on racking resistance and stiffness of the wall elements. For the first sample, the float glass panes were made in one piece in dimensions of 2.11m x 2.03 m and for the second sample, the float glass panes were made in two pieces in dimensions of 0.99 m x 2.03 m each. Each of the insulation glass panels were made of three 6 mm thick glass panes **(3.17)**. The polyurethane adhesive which applied circumferentially around the glass panel into a groove in the timber frame, was used. Besides the monotonous horizontal point loading, an additional vertical load of q = 25 kN/m was applied onto the specimens.

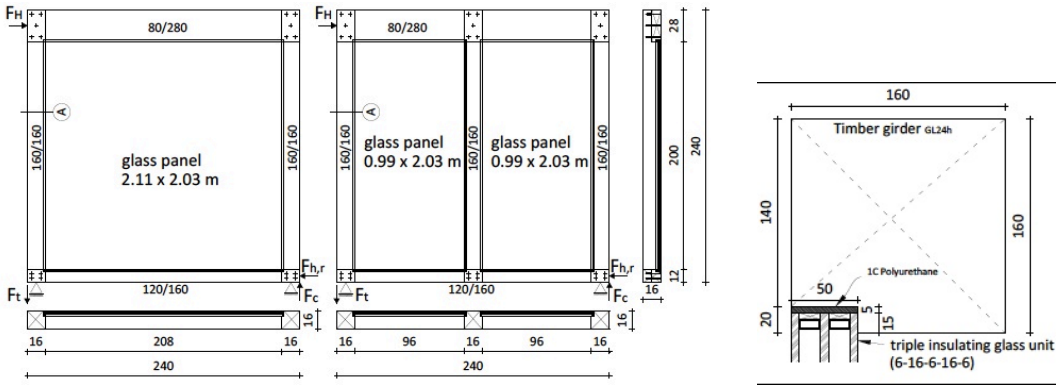


Figure 3.17 : Geometry of the specimens and cross-section from the testing groups (Ber, 2014).

It is clear from the given results that the first sample demonstrated a higher racking strength (for 16.6%) and especially essentially higher stiffness (for 78.3%) than second one. The second sample demonstrated essentially higher ultimate deformation and consequently a higher ductility. The both samples demonstrated a very similar kind of failure in the following stages: destruction of the bonding line, destruction in

the corners of the timber elements connections and glass failure. The test samples were further used for the cyclic tests. In determining the loading protocol, ultimate values of displacements from the previous analyse monotonic tests were taken into account. The result of cyclic tests indicated the racking resistance (Fmax) decreased in average for 14.4% for first type samples and for 10.7% for second type test samples according to the monotonic test results. The ultimate horizontal displacement was also decreased for each sample compare to the monotonic test results. It is evident from the presented results as well as from the failure modes that these types of bonding line conditions and the polyurethane adhesive can demonstrate a quite ductile type of failure which assured a quite high range of post-breaking resistance of all test samples (Ber, 2014).

A series of experiments were performed on the shaking table of the IZIIS institute in Skopje, Macedonia under a common guidance of University of Maribor (Ber, 2013b). The aim was not limited only to proving the load-bearing capacity of the wall elements under a monotonic static and dynamic point load, where the elements are tested in 2-dimensions only, but further to extend research in behaviour of the timber-glass wall elements incorporated into a 3-dimensional real timber box-house model which was seismically loaded on the shaking-table. The box model consist of the timber-glass wall elements as well as of the timber-framed wall elements with classical OSB sheathing boards which proved essentially higher racking resistance and stiffness under the monotonic point load than the timber-glass wall elements. Four types of such walls were used **(3.18)**. Insulation glass panel has three 6.0 mm float glass panes with 16 mm free space between the pains which is not filled with the gas. Adhesive layer is made of 5.0 mm thick one-component polyurethane adhesive. Light timber frame wall elements with classical OSB sheathing board consist of timber frame and 12.0 mm thick oriented strand board stapled onto the timber frame (Ber, 2013b).

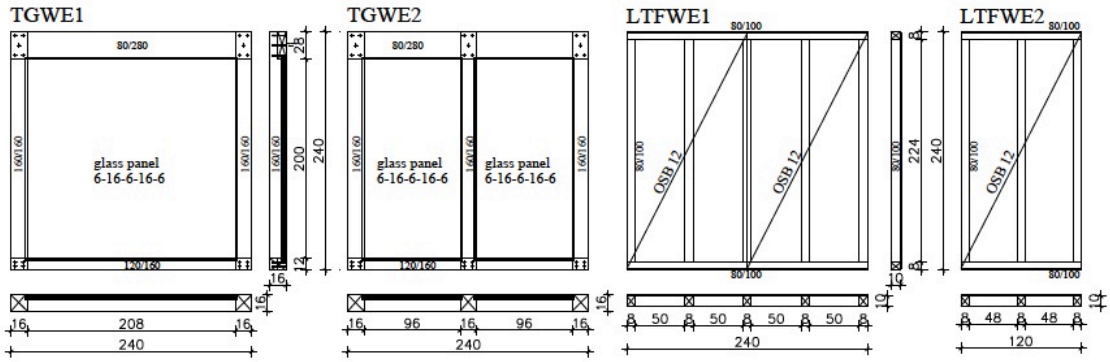


Figure 3.18 : Dimensions of timber-glass and light timber frame wall elements (Ber, 2013b).

Various combinations of single-storey (total height of 2.5m) and two-storey (total height of 5m) model structures were tested by combining different wall setups **(3.19)**.

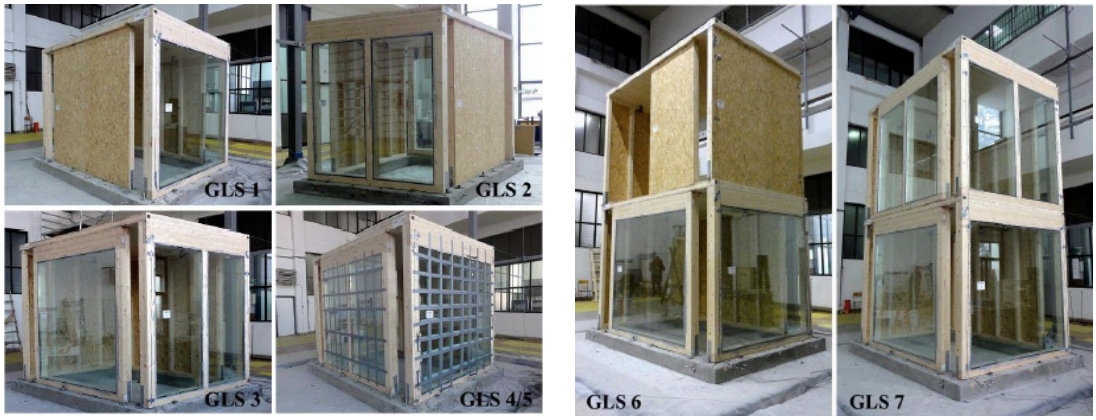


Figure 3.19 : Configuration of single-storey and two-story test models (Ber, 2013b).

The testing series was divided into two basic modules; low-intensity testing where the structure remained undamaged and in an elastic state of the material behaviour (including all the connections) and high-intensity testing where the ground acceleration was scaled up enough to cause failure in the structure. Before and after each earthquake simulation sine sweep test with frequencies in the range of 1-32 Hz and intensity of 0.01g was applied in order to clearly calculate the vibration period of the structure and to record the response of the building.

The result of seismic tests presented that there was only a slight change in the measured first periods before and after excitation by all tested models. This can prove that there was only a small decrease in a horizontal stiffness of the tested models which can be the first indicator that the deformation range in the structural elements and connections was not essentially high. A visible type of the observed

deformations in all structural elements as well as connections to the foundation and between the floor. A shear slip of maximum 1 mm was present in the adhesive between the glass panel and the timber frame, however seal remained undamaged. Considering the given facts, the polyurethane adhesive could behave very ductile and resisting also under the seismic loads (Ber, 2013b).

3.2 Monotonic and Cyclic Tests of Large Size Specimens

Timber-framed structures have a mechanism that the permanent and snow loads are supported by the vertical members and that the wind and seismic loads are resisted by the shear wall system. Structural performance of timber-framed shear walls are mainly determined by the mechanical properties of sheathing materials, joints connecting sheathing materials to timber frames and those connecting shear walls to the foundation. Within the research project, the glass pane has same force distribution behaviour like the classical timber sheathing boards. The adhesive takes over the shear stresses in the bonding line (shear connecting area on the scheme in **3.20**) and joint elements resist compression, then allow the respective forces to the glass that can be transmitted in a diagonal direction along the glass pane. The tensile diagonal of the glass pane shifts the force to the support (board tensile diagonal on the scheme in **3.20**).

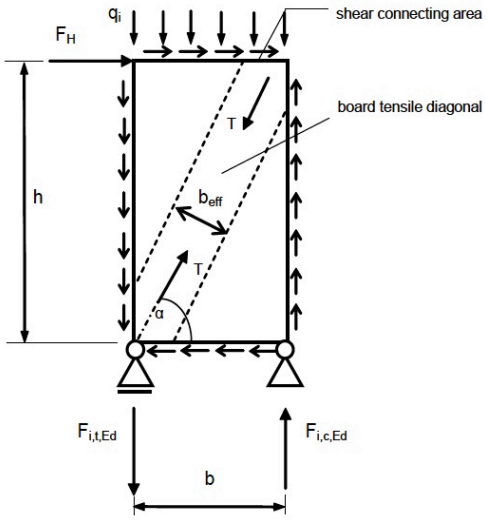


Figure 3.20 : Sheme of the force distrubation (Leskovar, 2013).

Thus, the horizontal point load acting at the top of the element is transferred to the supports. Against the static loads (dead load, live load, snow, etc.), the system must

provide a high ductility and assure a high static resistance as well. The load-bearing capacity of the shear wall elements under monotonic and cyclic load were tested and given in this chapter.

3.2.1 Experimental Materials and Methods

3.2.1.1 Materials and their properties

For the materials of the large size specimens, birch plywood, tempered soda-lime glass with a thickness of 8 mm and and two-component silicone and epoxy adhesive was used.

3.2.1.1.1 Plywood

Birch Plywood was used within the experiments of large size specimens. A common hardwood species used for plywood production is birch. Birch plywood is characterised by its excellent strength, stiffness and resistance to creep. It has a high planar shear strength and impact resistance, which make it especially suitable for heavy-duty floor and wall structures. Birch plywood has excellent surface hardness. Properly surfaced and edge sealed birch plywood also offers excellent weather and moisture resistance. The advantage with birch is its fast rate of growth (30-35 years) compared to other wood species, e.g., spruce (Terzieva, 2008).

The plywood classified surface grade III (EN 635-2) and water boiled proof (EN 314-2). The plywood specimens were stored at a constant climate of +20 °C and 80 % relative humidity prior to bonding.

3.2.1.1.2 Glass

Tempered soda-lime glass was used as substrate material of test specimen. The higher strength compared to standard float glass minimizes glass failure during testing. The tempering of the glass does not change the adhesive characteristic of its surface. For this test sequence glass is always glued on the air-side. The surface was cleaned by a solvent. No further surface treatments were executed. The tempered glass for the experiments in Istanbul is produced in the Trakya Glass Industry fabric (Trakya Cam Sanayii A.S.).

3.2.1.1.3 Adhesives

The structural silicone adhesive, Ottocoll S660 which is soft adhesive with initial modulus of elasticity under 10 MPa, was used within the experiments. The sealant Ottocoll S660 was specifically developed for timber glass composites by the adhesive manufacturer Otto Chemie. Ottocoll S660 exhibits good durability, although it is rather soft. This may limit its applicability for shear walls and other structural purposes with high loads. Nevertheless, it is important to gain further knowledge on its creep behavior and durability to avoid additional mechanical fixing for dead load support and bondline failure.



Figure 3.21 : Ottocoll S660 and its compressed air gun
(Otto Chemie Professional Guide, 2014)

Ottocoll S660 has characteristics: Neutral, condensation curing 2-component silicone adhesive and sealant based on alkoxy, crack and notch resistant, non-corrosive, excellent adhesion on glass and wood, high expansion-tension value guarantees high stability bonding, cures at room temperature, minimal odour nuisance, the fast curing, high mechanical capability, low shrinkage during vulcanization, very good temperature and UV resistance and excellent resistance to water and moisture (Otto Chemie Professional Guide, 2014).

3.2.1.2 Test Methods

3.2.1.2.1 Test Configuration

The dimensions of the specimens and test setup were selected to be compatible with the previous experimental work perfomed by TU Vienna, (Hochhauser, 2011b). The idea was to obtain and evaluate test data of cyclically loaded timber-glass specimens comparatively with the monotonic loaded specimens of TU Vienna.

Four timber-glass specimens were fabricated for quasi-static tests with birch plywood, 8 mm thick tempered glass and two-component silicone adhesive Ottocoll S660. Epoxy was used at the corners of the specimens in order to transfer lateral load from plywood to glass properly instead of silicone adhesive. The section of birch plywood was L-shaped and the thickness of adhesive was 3 mm. The coupling strips of birch veneer plywood were mitred and positioned with a gap width of 5 mm apart. Plywood elements are not combined at the edged, so that the effect of general behavior of the combination on horizontal loads are removed as a parameter. The dimensions of tempered glass were 1.25m x 2.5m. The details of large size specimens are given in Figure **(3.22)** and **(3.23)**. Fabrication of all specimens was done by ITU team with the help of professional workers from Metal Yapı A.S. **(3.24)**. Firstly, the block area distance 20 cm from each glass corners and the distance 5.0 cm. between glass corners and the beginning of the block was determined with a thin adhesive tape. Epoxy was used at these block area, so the setting blocks only able to transfer compressive forces.

Then the two-component silicone adhesive was applied with a pneumatic gun into an empty linear slot between the timber frame and the glass pane except the epoxy areas, as it is presented in Figure **(3.23)**. The specimens were held in same place for one months in order to guarantee proper curing of adhesive.

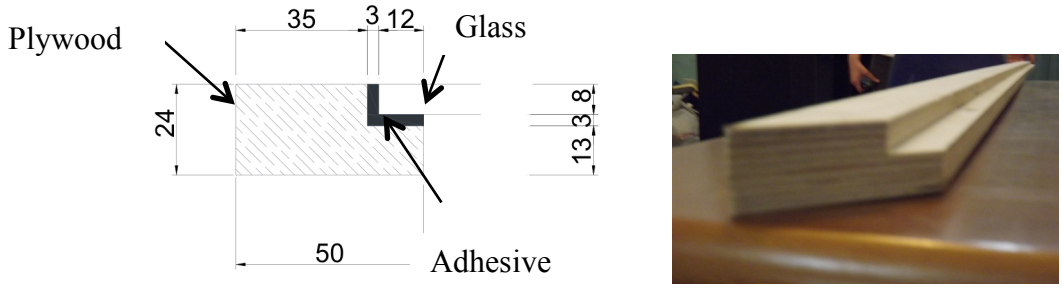


Figure 3.22 : Cross-section of large size timber-glass specimens (Units are in mm.).

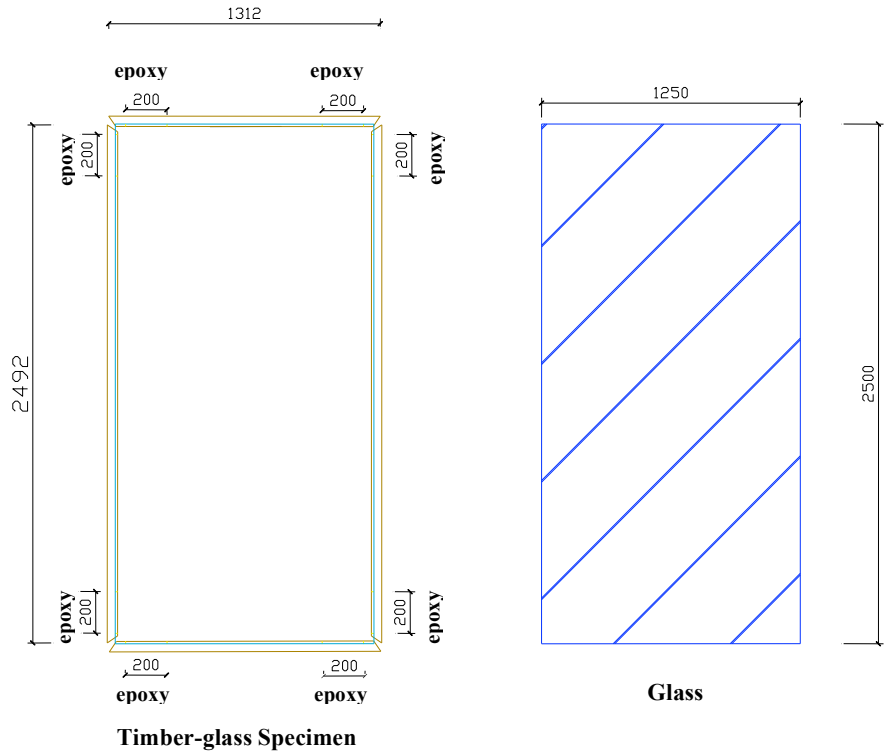


Figure 3.23 : Details of large size timber-glass specimens (Units are in mm.).

One of the specimens was selected as the reference specimen to be loaded monotonically. Second of the specimens was also tested under monotonic lateral loads. The other specimens were planned to be tested under cyclic lateral loads (load in compression and tension).



Figure 3.24 : Fabrication stage of large size timber-glass specimens.

In-plane lateral loads were applied to the specimens via a steel loading frame. Steel loading frame has been fabricated similar to the TU Vienna test setup with some modifications **(3.25)**. Steel frame elements were hinge connected. Steel loading

frame were loaded horizontally by using an actuator **(3.26)** and **(3.27)**. Timber-glass specimens were attached to loading frame by using multiple timber nails.

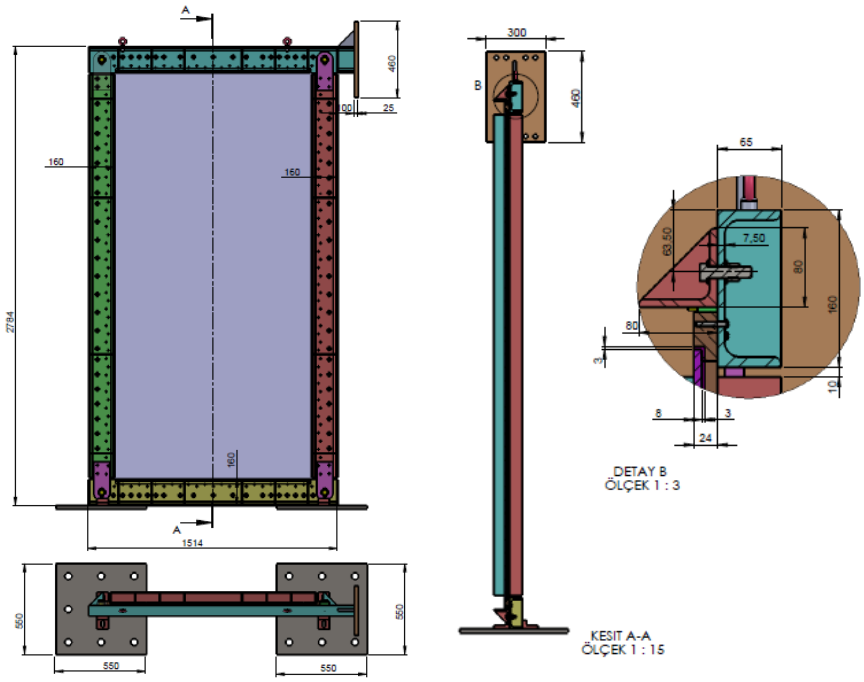


Figure 3.25 : Steel loading frame (Units are in mm).

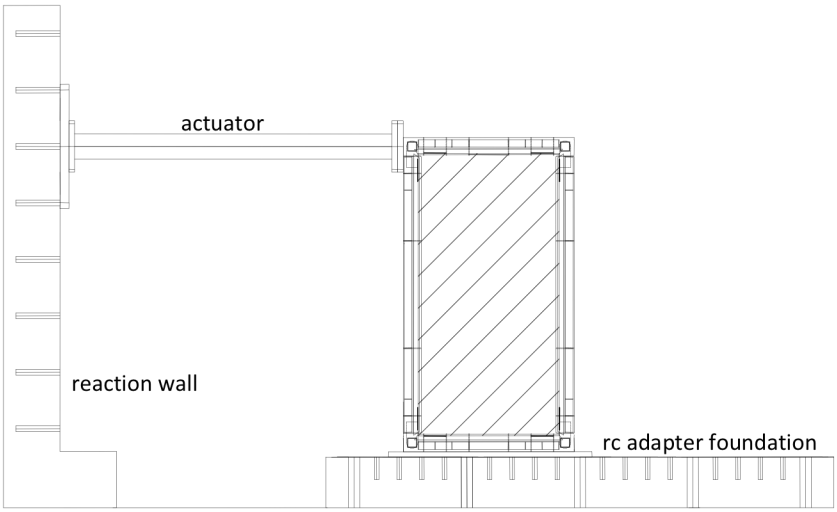


Figure 3.26 : Lateral loading of large size timber-glass specimens.



Figure 3.27 : Test set up large size timber-glass specimens.

3.2.1.2.2 Loading Procedure

Loading protocol of monotonic tests were according to `BS EN 594:1996 Timber structures — Test methods — Racking strength and stiffness of timber frame wall panels `. This version of the standard was used to have the same loading protocol with TU Vienna tests. Force controlled monotonic loading was consisted of three parts, namely, `stabilising load cycle`, `stiffness load cycle` and `strength test` **(Table 3.1)** and **(3.28)**. For monotonic tests, estimated maximum racking load, $F_{max,est}$, was taken as 50 kN based on previous studies.

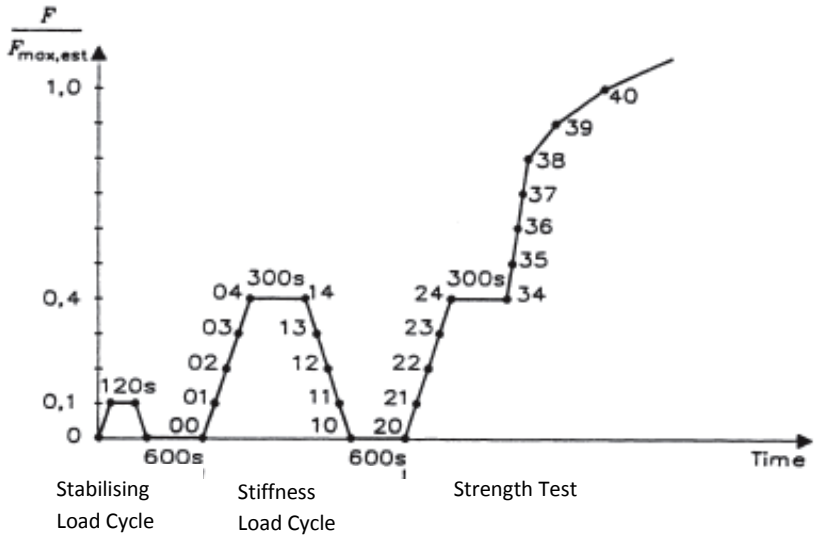


Figure 3.28 : Monotonic loading protocol as given in BS EN 594:1996.

Table 3.1 : Loading steps of monotonic tests.

Load Step	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Load (kN)	0	5	5	0	0	20	20	0	0	20	20	Increasing Loads

The loading protocol given in `BS EN 12512:2001 Timber structures — Test methods — Cyclic testing of joints made with mechanical fasteners` was used for displacement controlled cyclic tests **(3.29)**. Estimated yield slip was determined as V_y=4.16mm from monotonic tests and target top displacements were calculated using this value **(Table 3.2)**. First two target displacements were applied for only one cycle (one pushing and one pulling). Further target displacements were applied as three sets of cycles. According to the observations made during the tests, load steps $2{,}5V_y$, $3{,}0V_y$, $3{,}5V_y$ and $5V_y$ were added to loading protocol with the intention of obtaining a more detailed information about the behavior and damage of the specimens.

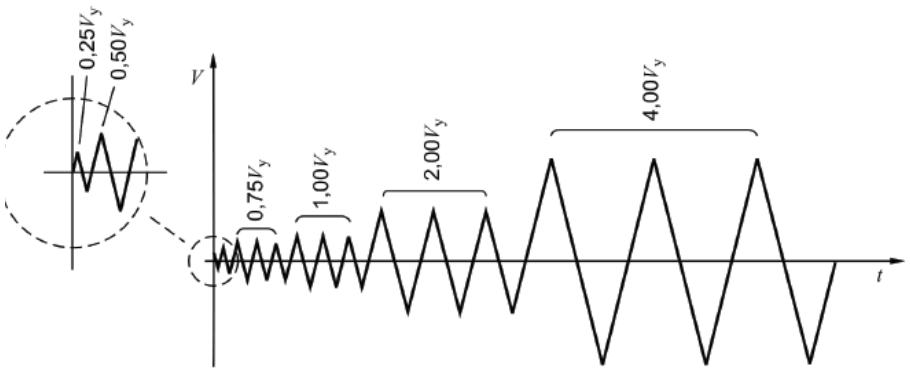


Figure 3.29 : Cyclic loading protocol as given in BS EN 12512:2001.

Table 3.2 : Loading steps of cyclic tests.

Load Step	**No of Cycles**	**Target Top Displacement Ratio (V_y=4.16 mm)**	**Target Top Displacement (mm)**
1	1	$0{,}25V_y$	1,0
2	1	$0{,}50V_y$	2,0
3	3	$0{,}75V_y$	3,1
4-5-6	3	$1{,}00V_y$	4,1
7-8-9	3	$2{,}00V_y$	8,3
10-11-12	3	$2{,}50V_y$	10,4
13-14-15	3	$3{,}00V_y$	12,4
16-17-18	3	$3{,}50V_y$	14,5
19-20-21	3	$4{,}00V_y$	16,6
22-23-24	3	$5{,}00V_y$	20,8

Lateral top displacements, strain values of timber and glass were measured by LVDTs (transducers) and straingauges and recorded during the test **(3.30)**. Displacements of adhesive bond line were measured by Pi-gauges. Rotation of steel frame and relative displacement of steel to timber were measured by LVDT`s as well. Out-of-plane displacements of the specimen were measured and controlled during the test.

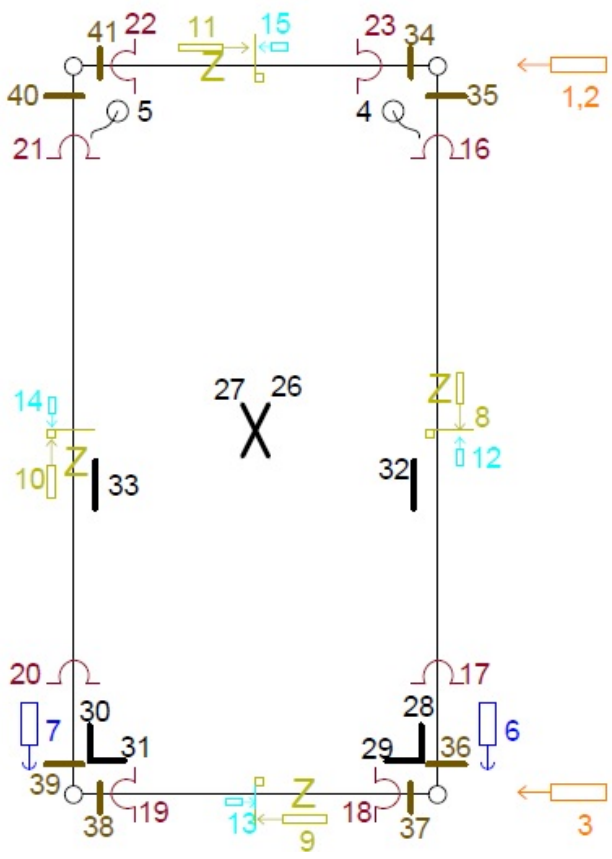


Figure 3.30 : Measuring devices schema of large size specimen tests.

The displacement of the steel frame at head and below were measured with three transducers (number 1, 2, 3). The displacement of the specimen out of the plane were measured with two transducers (number 4, 5). Two transducers (number 6, 7) were used for measuring the vertical displacement. Four transducers (number 8, 9, 10, 11) were determined the relative displacement between timber and glass. The relative displacement between timber and steel were measured with four transducers (number 12, 13, 14, 15) **(3.30)**, **(3.31)**. Eight Pi-gauges were used for measuring the displacements of adhesive bond line (number 16, 17, 18, 19, 20, 21, 22 and 23) **(3.30)**, **(3.32)**. Strain values of glass were measured with straingauges (number 26, 27, 28, 29, 30, 31, 32 and 33) while strain values and elongation of timber were measured with straingauges (number 34, 35, 36, 37, 38, 39, 40 and 41) **(3.30)**, **(3.33)**. Especially, the elongation of the glass in the tension diogonal area (in the middle) and the compressive stress in the corner of the glass were measured in two directions.



Figure 3.31 : Transducers for measuring the displacement on specimen (respectively from left to right 1,2 and 5, 6, 8, 11 and 12 are given).

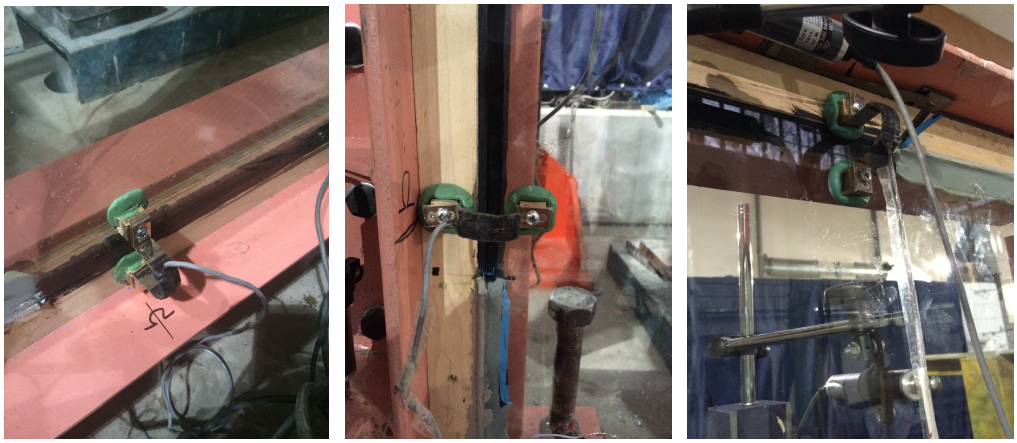


Figure 3.32 : Pi-gauges for measuring the displacement adhesive bond line (respectively 19, 21 and 23 are given).



Figure 3.33 : Straingauges for measuring the strain values and elongation timber and glass (respectively 26, 27 and 28, 29 and 33 are given).

Then all the cable of measuring devices were connected the switch box for sending result data to programme **(3.34)**.



Figure 3.34 : Connection of the switch box.

3.2.2 Experimental Tests

As mentioned above, first reference specimen (SPM-1) was loaded monotonically and early failure of the specimen was due to the torsional effects of out-of-plane displacements. Maximum lateral load and top displacement values of SPM-1 is 13,78kN and 14,48mm, respectively. Failure mode of SPM-1 was the brittle failure of glass **(3.35)**.

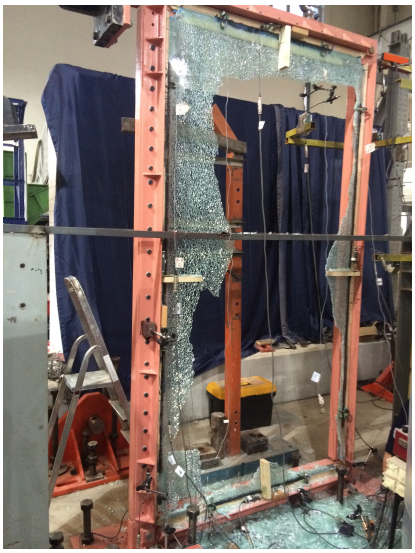


Figure 3.35 : Failure mode of SPM-1.

Therefore the test setup was modified and out-of-plane displacements of specimen were restricted by utilizing an additional steel frame **(3.36)**. One of the three specimens left was selected as the reference specimen (SPM-2) and loaded monotonically, while the other two (SPC-1 and SPC-2) were to be tested under cyclic lateral loads.

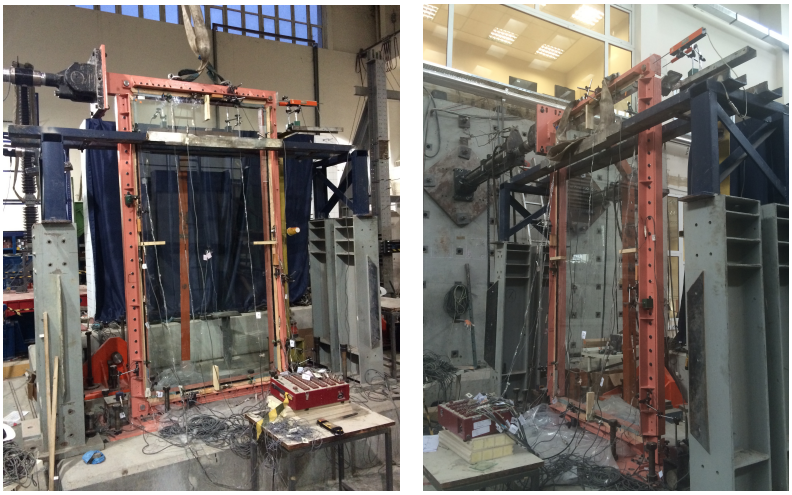


Figure 3.36 : Test configuration after the additional steel frame.

Second reference frame (SPM-2) was tested under monotonic lateral loads. Lateral load-top displacement diagram of the specimen is given in Figure **3.37**. Failure occured while loading was in the `stiffness load cycle` phase. Maximum lateral load and top displacement values of SPM-2 is 16,97kN and 8,52mm, respectively. Racking stiffness of the specimen was calculated as R_{M2}=1788,43N/mm by using the formula given in `BS EN 594:1996`.

Racking stiffness of the panel, calculated from the equation:

$$R = \left[\frac{F_4 - F_2}{v_4 - v_2} \right]_{\text{N/mm}} \tag{3.1}$$

F2 is the racking load of 0,2 Fmax, in Newtons;

F4 racking load of 0,4 Fmax, in Newtons;

v2 and v4 is the deformation, in millimetres (BS EN 594, 1996).

Failure mode was the brittle failure of the glass under compression loads **(3.38).** Epoxy adhesive transferred compression forces from timber to glass successfully as required. Nevertheless, rigid behavior of epoxy prevented the movement of the glass at the corners which led to the failure of tempered glass, thereby the specimen. As a result, lateral load capacity of the specimen were less than expected. Failure mode of SPM-2 is defined as `diagonal compression failure of glass`.

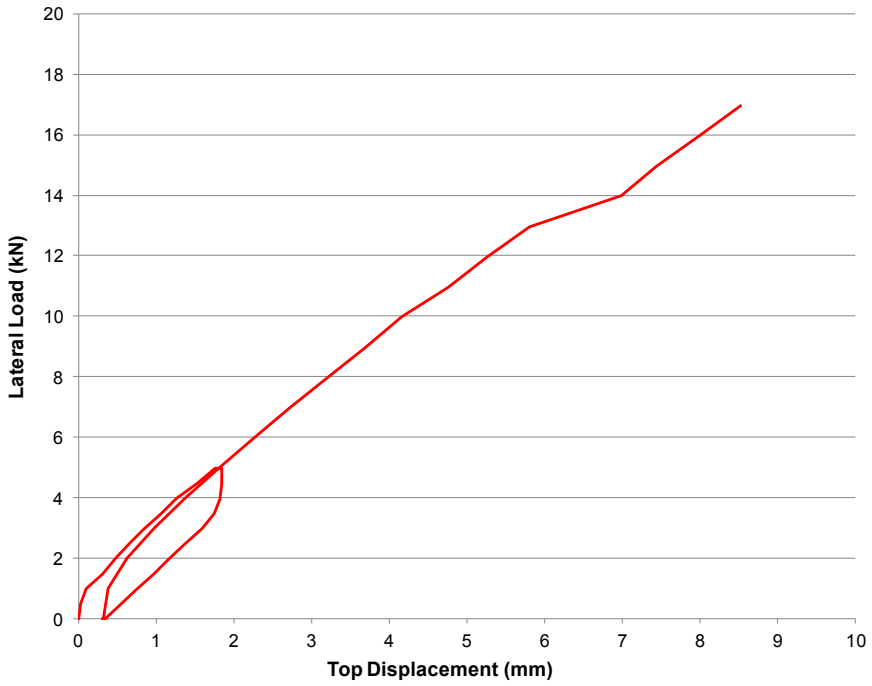


Figure 3.37 : Lateral load-top displacement diagram of SPM-2.



Figure 3.38 : Failure mode of SPM-2.

Third specimen (SPC-1) was subjected to cyclic in-plane lateral loads. Lateral load-top displacement diagram of the specimen is given in Figure **(3.39)**. Firstly, at 1th cycle, applied the load in compression, until a slip of 25 % of the estimated yield slip Vy is reached. The value of Vy was be evaluated by calculation by previous monotonic tests according to EN 26891 and estimated yield slip was determined as Vy=4.16mm from monotonic tests. Then, the specimen was unloaded and reloaded in tension to zero-slip and continue to load in tension up to a slip of 25 % of Vy on the tension side, then it unloaded and reloaded in compression to zero-slip again. At 2th cycle, the load was applied in compression up to a slip of 50 % of Vy and it unloaded and reloaded in tension to zero-slip. Then it was continued to load in tension, up to a slip of 50 % of Vy and it unloaded and reloaded in compression to zero-slip again. . At 3th cycle, it was loaded in compression and also in tension up to a slip of 75 % of Vy at three times. At 4th, 5th, 6th cycles the load was applied three times but corresponding to Vy. At following set of three cycles the load was applied three times but different values of Vy **Table 3.2**. Failure of the specimen occured at 5,0Vy load level (24th step). Maximum lateral load and top displacements of SPC-1 are 18,89kN and 20,77mm for pushing and 19,16kN and 21,00mm for pulling, respectively. Envelope of lateral load-top displacement diagram was produced by connecting the peaks of first cycles of each loading step **(3.40)**. Racking stiffness of the specimen was calculated from this envelope for pushing and pulling. Racking stiffness are RC1+=1085,83 N/mm and RC1-=1185,29 N/mm for pushing and

pulling respectively. Ultimate lateral load and top displacements for pushing and pulling are 8,71kN, 20,64mm and 2,97kN, 21,12 mm, respectively.

During the test of SPC-1, failure of the bondline was observed both at the epoxy and the silicone. At the final load steps, glass seperated even from the epoxy connected areas substantially. Abrupt decreases of load occurred at the final cycles ($5{,}00V_y$), while the seperation of the glass became clearly visible. After the 2nd cycle of load step $5{,}00V_y$ completed, lateral load capacity of the specimen dropped nearly to 15% of F_{max}. At that point, test was finished as the specimens did not work as a timber-glass composite wall any more **(3.41)**. Failure mode of specimen SPC-1 was defined as `failure of bondline and sliding of glass afterwards`.

Specimen SPC-2 were planned to be loaded under cyclic loads, but during the instalation stage of the specimen to the steel loading frame, tempered glass broke suddenly. Due to the limited time, fabrication of a substitute specimen was not possible.

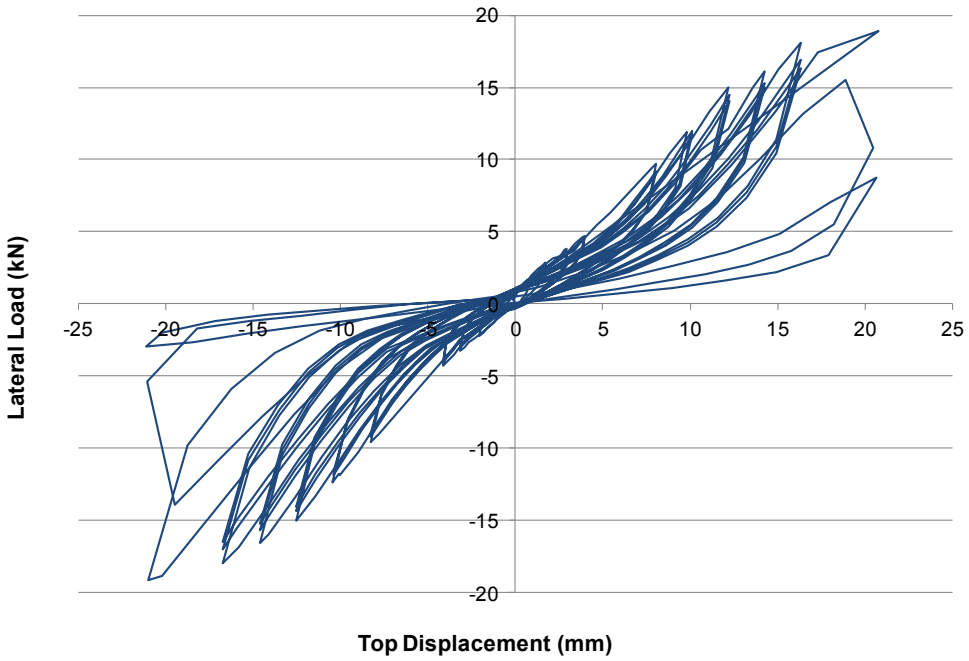


Figure 3.39 : Lateral load top displacement diagram of SPC-1.

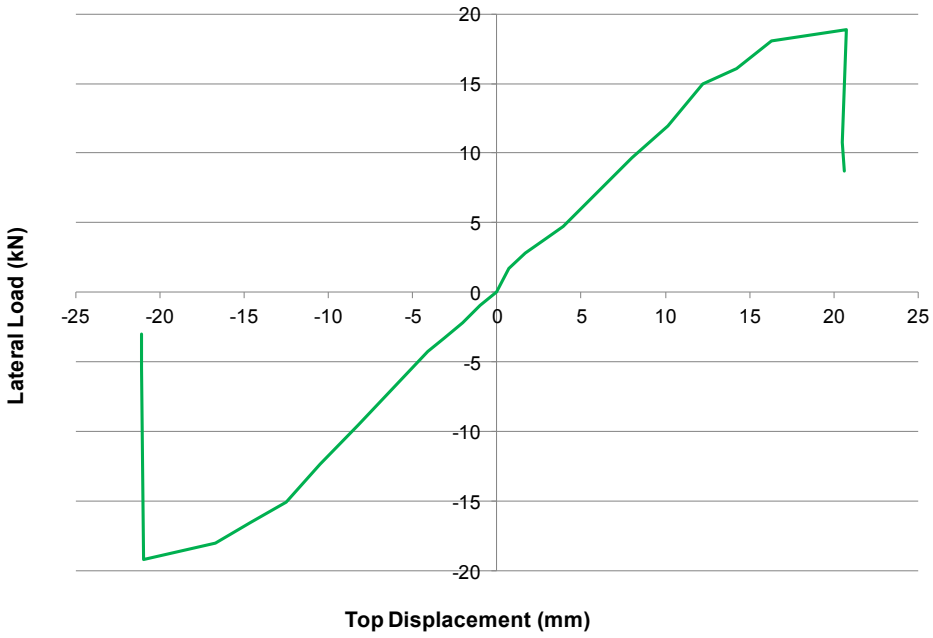


Figure 3.40 : Lateral load top displacement envelope of SPC-1.



Figure 3.41 : Failure mode of SPC-1.

3.2.3 Test Results

In order to compare the test results of specimens SPM-2 and SPC-1, lateral load-top displacements are shown together in Figure **(3.42)**. Test results are also summarized in **Table 3.3**. It can be observed that racking stiffness of monotonically loaded specimen (SPM-2) is bigger than cyclic loaded specimen (SPC-1), as expected. Though, lateral load and displacement capacities of SPC-1 are bigger than SPM-2. Maximum lateral displacement of SPC-1 is approximately 2,45 times of SPM-2. The racking stiffness of pulling is bigger than the racking stiffness of pushing in cyclic loaded specimen (SPC-1) **Table 3.3**. According to this, it is observed that timber glass composite shear wall has a higher rate of rigidity under monotonic loading.

Furthermore, breakage of glass caused by rigid epoxy behavior at corner bondlines that led the specimen to brittle failure was overcome by cyclic loading. Pushing and pulling of incremental load cycles of SPC-1 allowed the glass to seperate from epoxy and silicone bondline step by step.

It should be pointed out that cyclic loading pattern is a more realistic approach than monotonic loading for simulating lateral loads, such as earthquake and wind loads. The promising test results of SPC-1 shows that more cyclic tests should be performed by researchers in order to investigate real behavior of timber-glass composite walls in the near future.

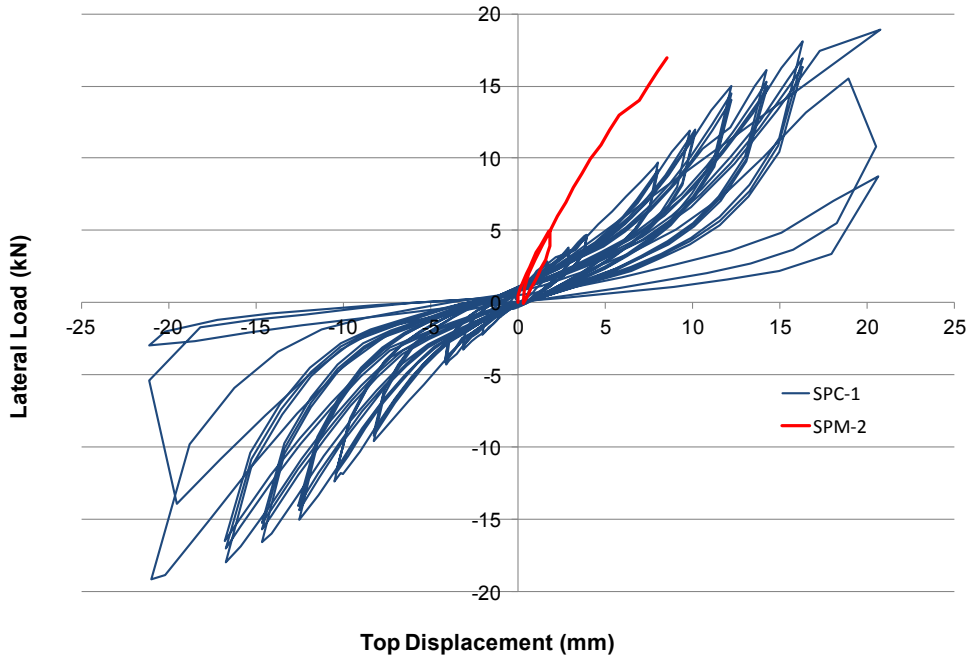


Figure 3.42 : Lateral load- top displacement diagrams of SPM-2 and SPC-1.

Table 3.3 : Test results of SPM-2 and SPC-1.

Specimen	F_{max+} [1] (kN)	F_{max-} [2] (kN)	Δ_{max+} [3] (mm)	Δ_{max-} [4] (mm)	R_+ [5] (N/mm)	R_- [6] (N/mm)	Failure Mode
SPM-2	16,97	-	8,52	-	1788,43	-	Diagonal compression failure of glass
SPC-1	18,89	19,16	20,77	21,00	1085,83	1185,29	Failure of bondline and sliding of glass afterwards

[1] F_{max+}: maximum lateral load for pushing, [2] F_{max-}: maximum lateral load for pulling, [3] Δ_{max+} : maximum displacement for pushing, [4] Δ_{max-} : maximum displacement for pulling, [5] R_+ : racking stiffness for pushing, [6] R_- : racking stiffness for pulling.

3.2.4 Comparison of Test Results with Previous Test Results

When the results are compare to the results of the participants of the study carried out in Slovenia, Cruz (2007), it is observed that the failure of the test samples are similar, such as the timber-glass elements with a stiff adhesive (epoxy) are completely brittle with a glass rupture in the compressive diagonal and with elastic adhesives failed because of the adhesive yielding. The calculated results for the racking stiffness is R=686,76 N/mm and maximum lateral load Fmax =28,28 kN for timber glass composite elements with silicone and polyurethan adhesive but they have different joint type and different glass thickness which was 10 mm **(3.43)**. Test specimens were exposed by the vertical piston as well as the lateral load.

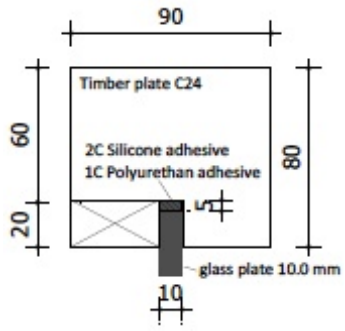


Figure 3.43 : Cross-section of specimen with silicone and polyurethan adhesive (Cruz, 2007).

Moreover, when the results are compared to the results of the participants of the study carried out in TU Vienna Austria, Winter and Hochhauser (2011a) it is seen that different glass type (float glass) and different joint type (only one side, 3/14 mm) were used. Their experiments were tested under only the monotonic loadings. Test results under monotonic loading, the racking stiffness is R=683 N/mm and maximum lateral load F=20,58 kN for timber glass composite elements with silicone and epoxy adhesive in timber configuration whereas with steel configuration the racking stiffness is R=1952 N/mm and maximum lateral load F=40,13 kN. Further, for acrylate adhesive with steel configuration racking stifness is R=3649 N/mm and maximum lateral load is F=74,37 kN. Consequently, using the rigid adhesive (epoxy, acrylate) has high racking resistance and stiffness, but high deformability and ductility between timber and glass needs to be provided, particularly at high temperature difference, as these two materials have substantially different mechanical properties under the temperature effect.

3.3 Long Term Loading Test of Medium Size Specimens

The research work of this project focuses on timber-glass composite shear walls in the building envelope. In general, the bondline of such composite elements is exposed to long-term static loading. Adhesives exhibit not only a load-dependent but also a time-dependent material behavior. The aim of medium size tests is to determine the creep behavior of timber-glass composite elements under long-term loading at outdoor conditions.

3.3.1 Experimental Material and Methods

3.3.1.1 Materials and their properties

For the medium size specimens, birch plywood, tempered soda-lime glass with a thickness of 8 mm and two-component silicone adhesive Ottocoll S660 were used. The plywood was classified as surface grade III (EN 635-2) and water boiled proof (EN 314-2 class 3). The tempered glass was a production of Trakya Glass Industry (Trakya Cam Sanayii A.S.). These were all described in detail in Chapter 3.2.1.1.

3.3.1.2 Test Methods

The dimensions of the specimens and test setup were selected to be compatible with the previous experimental work perfomed by participants from TU Vienna. The geometry of the medium-sized test specimens was chosen according to the small specimens. The length of the bond was increased to 1000 mm compared to 50 mm at the small specimens. Besides test setup loading levels were determined according to ETAG002 (Guideline for European Technical Approval For Structural Sealant Glazing Systems) which states the approval and design procedure for structural silicones. A global safety factor (gtot) is 6.0 in there. Tension design stress (σdes) was finded that the characteristic breaking stress divided by the safety factor. When compare these medium-sized test specimens with TU Vienna, the different bond line thickness and width can be seen (3 mm /12 mm of the specimen in Vienna). The details of L-shaped sections of plywood are given in **(3.44)**. The dimensions of the glass of the medium size specimens were 50 cm x 100 cm **(3.45)**. L-sectioned timber elements were bonded to the both sides of the glass by silicone adhesive.

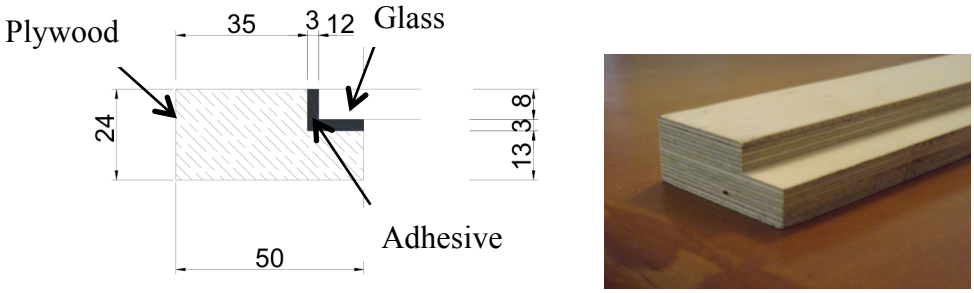


Figure 3.44 : Section properties of timber-glass specimens (Units are in mm).

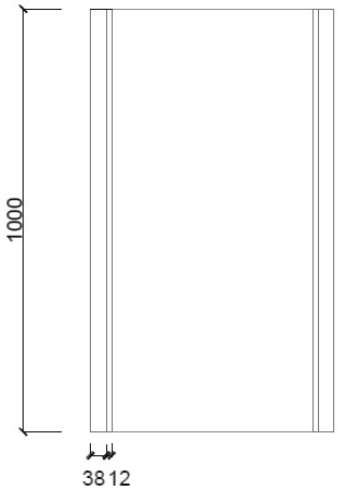


Figure 3.45 : Dimensions of medium-size specimens (Units are in mm).

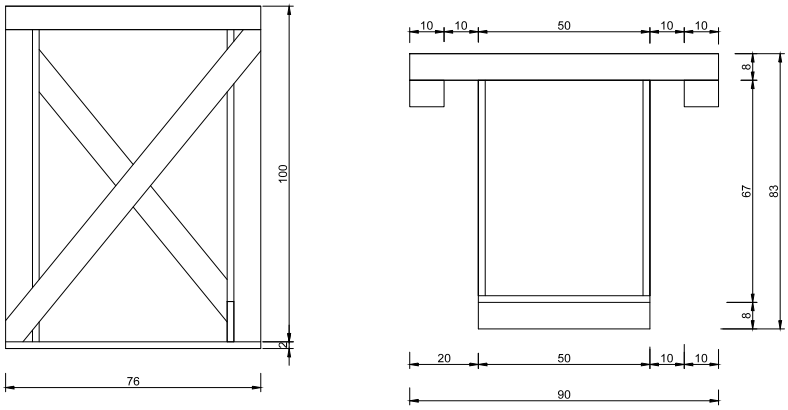
Fabrication of all specimens was done by ITU team with the help of professional workers from Metal Yapı A.S. **(3.46)**. As spacer, Thermalbond V2100 spacer tape which is made from a high-strength polyurethane foam and usually applied in structural sealant glazing systems, was used, as it can be see in blue color in Figure **(3.46)**. This has the advantage that the spacer can be removed after the bonding. In this case any influence of additional bonding of the spacer is suspended.



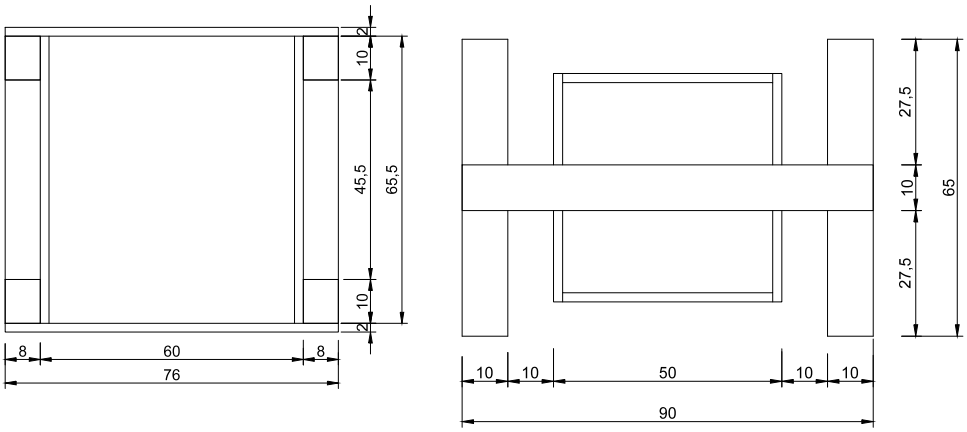
Figure 3.46 : Fabrication of medium-size timber glass specimens.



Figure 3.47 : Loading box details of medium size specimen test.



Front view Front view



Plan Plan

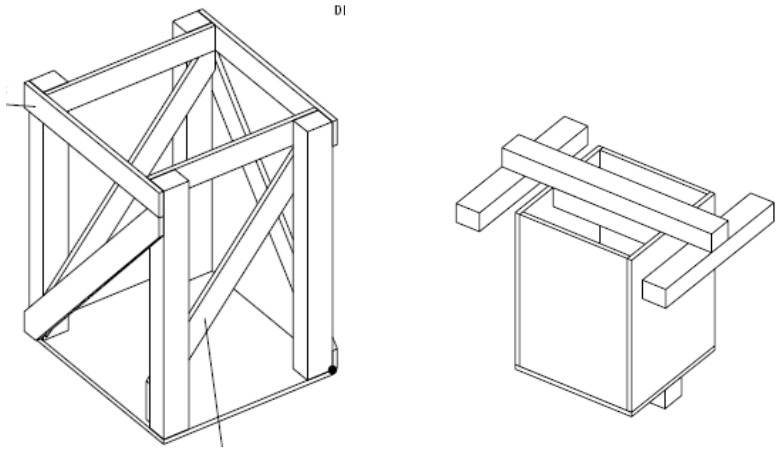


Figure 3.48 : Dimensions of the long term loading test set up (Units are in mm).

The experimental setup for long-term loading was prepared in the form of timber boxes. An unloaded timber box without fixed timber glass specimen is shown in Figure **(3.47)**, **(3.48)**.

Timber-glass composite specimens were attached to the loading boxes via pins from their plywood components. For each box, two timber-glass composite specimens were placed; one on the front and the other at the back side. Loading of the specimens were performed by filling the timber container with sand which is hanging from a timber beam. This beam is mounted on two other beams to transfer the load to the glass. For the measurement of the deformation, a horizontal aluminum bar was placed in the middle of the height of the specimen on each side. The entire experimental setup is shown in Figure **(3.50)**.

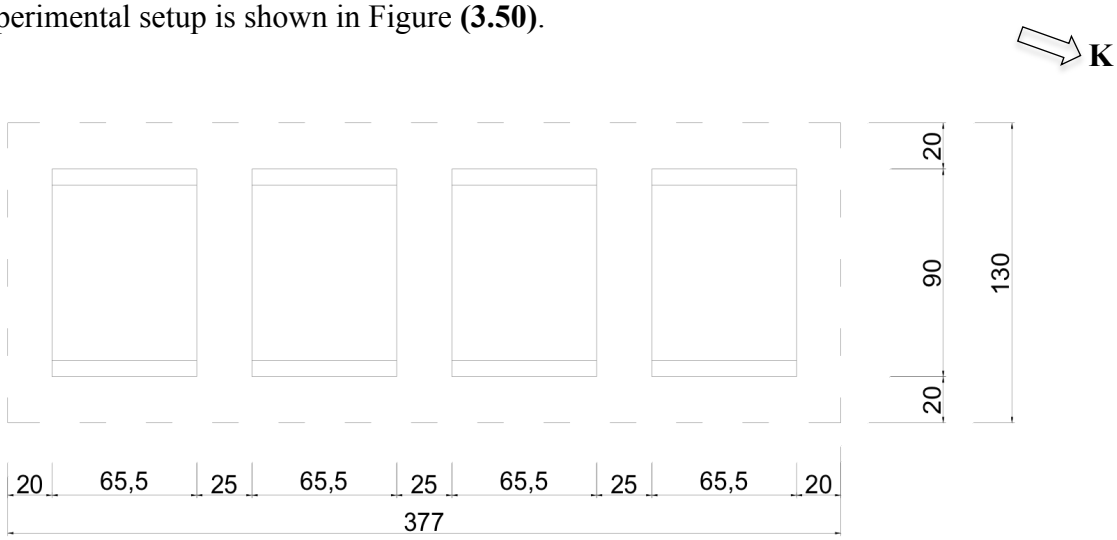


Figure 3.49 : Layout plan of medium-size specimens placed at exterior conditions. (Units are of cm.)



Figure 3.50 : Medium size specimen timber-glass specimens at exterior conditions

3.3.2 Experimental Tests

A total of 10 shear walls were made in the same sizes and details , two of them were planned to use for reference tests, the 8 others were screwed to the boxes as described before. Even though two different long term load levels were decided as 0,04 MPa and 0,05MPa, due to some difficulties during preparation of test setup real loading levels were 0,028 MPa (224 kg) and 0,035 MPa (280 kg). By this manner, four of the specimens were loaded under 0,028 MPa, while the other four specimens were subjected to 0,035 MPa during the first 174 days. The approximate adhesive area was 20x1000mm^2 and for two specimens under the same box loading, it was total 80.000mm^2.

During the test, vertical displacement of the glass was recorded once a day at the same time each day. Displacements were measured by mechanical displacement sensors (comparameters or measure gauge) which placed in a hole in the aluminum bar on middle level of specimen. In addition, the temperature and humidity were daily measured by automatic measuring device **(3.51)**.



Figure 3.51 : Mechanical displacement sensors (comparameters) and the temperature and humidity measuring device.

At the beginning of the experiment, the long-term loading test of medium-size timber-glass composite specimens was aimed to perform for six months. After 174 days of measurement, it was decided to increase the load on four of the specimens to 0,05 Mpa which was 0,028 MPa before **(3.52)**. For this, the specimens attached to the first loading box were replaced by the reference specimens that had been kept in laboratory conditions beforehand. The load of second box were also increased from 0,028 MPa to 0,05 MPa as well, but the specimens attached to this box were not

changed. So that 4 specimens were loaded with 400kg. The measurement of other loaded specimens under 0.035 MPa (280kg) continued as before.



Figure 3.52 : Increased load on the medium size specimens for long term loading at exterior conditions.

While the modifications were made for the loading of Box 1 and Box 2, the measuring setup of the tests and the measuring device were also modified. Displacements are now measured daily by digital comparameters to obtain more precise values **(3.53)**. It was measured during 12 weeks (90 days). The moisture percentage of plywood in each specimen is measured and recorded by an automatic device once a week **(3.53)**.



Figure 3.53 : Digital displacement measuring device (left) and automatic moisture measuring device (right).

3.3.3 Test Results

Two different climatic variations diagrams were obtained for the first 174 days and then for 12 weeks (90 days). The variation of temperature and relative humidity during the first 174 days of loading are given in **(3.54)**. Temperature changes were between min -2 °C and max 34.6 °C . Relative humidity was between 39% and 92%.

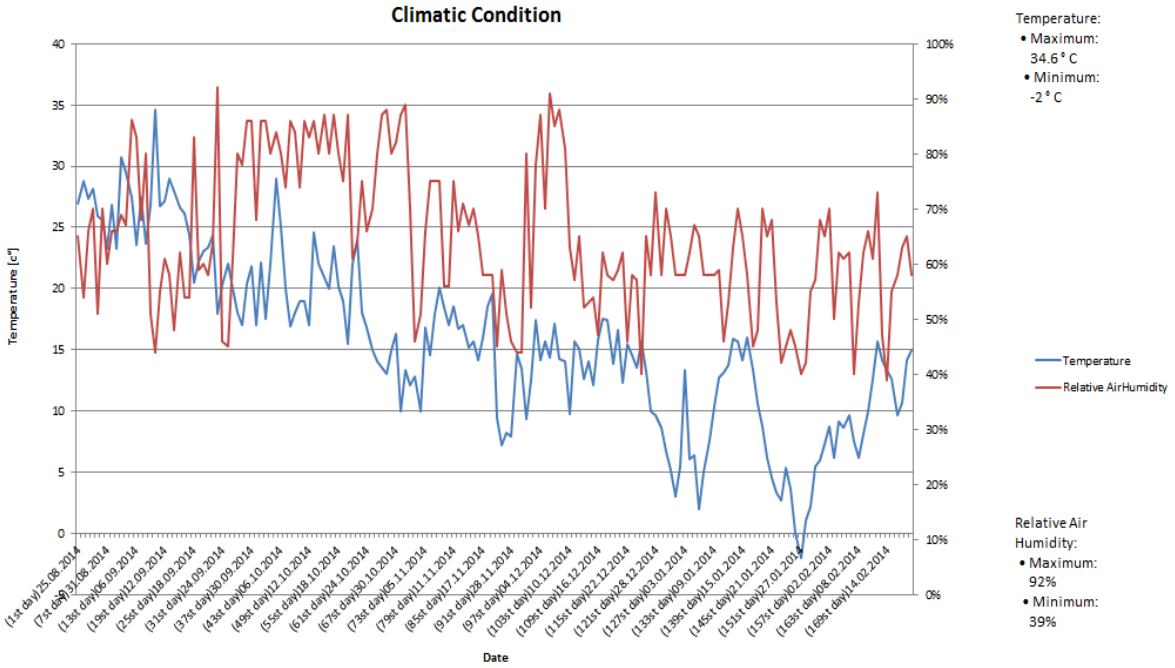


Figure 3.54 : Climatic variations diagram for the first 174 days.

The variation of temperature and relative humidity during 12 weeks (90 days) of loading are given in **(3.55)**. Temperature changes were between min 6.7 °C and max 26.1 °C . Relative humidity was between 33% and 73%.

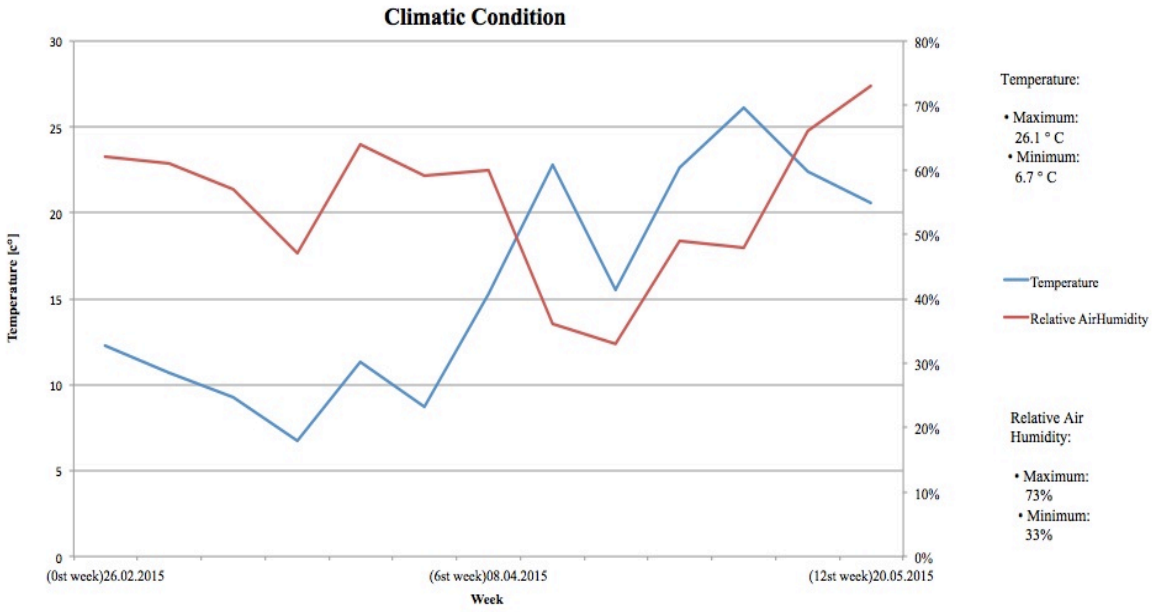


Figure 3.55 : Climatic variations diagram for 12 weeks (90 days).

Table 3.4 : Total vertical displacement values of medium-size specimen at the end of first 174 days.

Specimen No	Loading [1] (MPa)	Measurement Period [2] (Day)	Total Vertical Displacement (mm)
1	0.028	174	1.09
2	0.028	174	1.24
3	0.035	174	1.71
4	0.035	174	1.69
5	0.035	174	1,35
6	0.035	174	1.12
7	0.028	174	0.83
8	0.028	174	0.65

[1] Loading shows the amount of shear stress on each adhesive surface for specimens.

[2] Measurement period is the number of days between the first loading day and the final day of measurement.

Total vertical displacement values of specimens under long-term vertical loading measured at the end of 174 days (started on 25.08.2014) are given in **Table 3.4**.

It is clearly seen that the shear walls with the lower load level suffer less creep deformation than those with the higher load level. 1 and 8 specimens are under the same loading box (0.028), but these have different vertical displacement. The same situation is seen in the 2 and 7 specimens. In this case, the specimens 1 and 2 which are located in same direction (corresponds to the west) and exposed to same climatic influences (such as wind, daylight angles) , have more vertical displacement than the specimens (7 and 8) in the opposite direction. Likewise, 3 to 6 specimens and 4 to 5 specimens are under the same loading box (0.035). The specimens 3 and 4 which are located in same direction and exposed to same climatic influences, have more vertical displacement than the specimens (5 and 6) in the opposite direction **Table 3.4**.

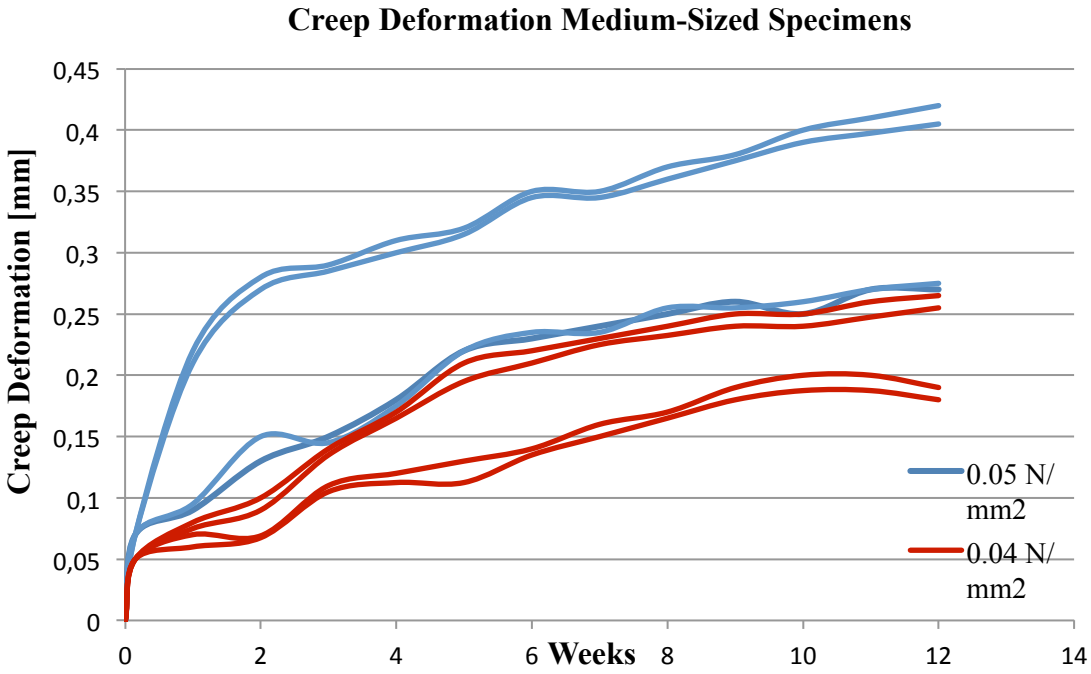


Figure 3.56 : Total displacements values of medium size specimen for the next 12 weeks (90 days).

It is clearly seen that the shear walls with the lower load level suffer less creep deformation than those with the higher load level.

At the end of 90 days, total vertical displacement value of medium-size specimens which were under 0,04 MPa loading is nearly 0.25 mm and displacement of the specimens which were under 0,05 MPa loading is nearly 0.40 mm **(3.56)**.

The vertical displacement of the glass and the moisture percentage of plywood are still measured twice a week. The moisture percentages of all specimens are varying between minimum %10 and %18 maximum. The specimens (5,6,7 and 8) which were located in back side and exposed to same climatic influences, have more moisture percentage of plywood than the specimens on the front side (1,2,3 and 4).

After one month later, all specimens will removed from the boxes and taken to the shear strength test to the laboratory. Further result will be obtained after the shear strength test.

3.3.4 Comparison of Test Results with Previous Test Results

When the results are compared with the results of the participants of the study carried out in TU Vienna Austria, it is observed that different glass type (float glass) and different joint type (only one side, 3/12 mm) were tested under constant temperature

of 16°C in the laboratory. Specimens were fixed on each box and the container in the middle of the box was filled with 245 kg respectively 196 kg (0,05 and 0,04 MPa) until seven weeks. The deformations of adhesive joints are average respectively 0,20 mm and 0,15mm. The comparison of results show that variable joint types have different strengths and resulting in different deformations value.

TU Vienna Austria also compared their medium size tests results with their results of the small specimens. It shows basically a similar creep behavior regardless of the length of the bond line, but in the average the deformation of the medium specimens is below the average of the small specimens. Apparently the small specimens achieve higher strengths than the medium ones. But the failure stress of the small specimens (mx = 1,168 N/mm.) is much higher than the failure stress off the medium sized specimens.

4. PILOT PROJECTS

This chapter comprises an overview of possible architectural design applications of timber and glass as composite structural materials. The objective is gathering the information obtained from literature review and experiment tests for designing pilot structures in the scope of them. The structural requirements and behaviors under lateral load (like earthquake) and long-term loading at environmental conditions are the most important issues to be considered while implementing pilot projects. These projects will provide the possibility to experience the practicality and applicability of developed composite systems, and create different design and application solutions. The pilot projects were developed with the use of timber-glass composite elements. The projects are bus stop, three different designs of a resting place in the same area, bagel kiosk and soldiers cabin.

4.1 Bus Stop

Transparent building elements where glass is used as a load-bearing member open up new design opportunities for buildings and its envelope. The main design idea of bus stop project is to demonstrate the benefits of using load bearing capacity of the LBTGC elements for a good example of application in buildings. An energy saving building can be designed by making use of the sunlight passing through the glass wall. The first approach is gathered the timber-glass shear walls together for use of the sunlight.



Figure 4.1 : The design of the bus stop.

This pilot project is designed to used for passengers and also bicycle parking. Total area is approximately 10 m^2. It is designed for every district in the city. The bus stop has four glass facades which provide transparency and aesthetic appearance **(4.1)**. For the materials of the bus station, birch plywood and tempered soda-lime glass with a thickness of 8 mm are used. The plywood is classified surface grade III (EN 635-2) and water boiled proof (EN 314-2 class 3). In addition to this, pilot project is performed using the silicone adhesive Ottocoll S660 for bonding plywood and tempered soda-lime glass. It exhibits a good durability, also rather soft. Ten panels of timber-glass shear walls (125x250cm) are planned to be used **(4.2)**, **(4.3)**.

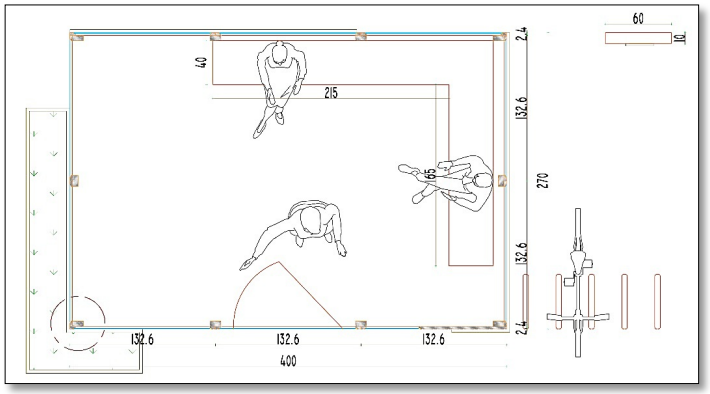


Figure 4.2 : The plan of the bus stop.

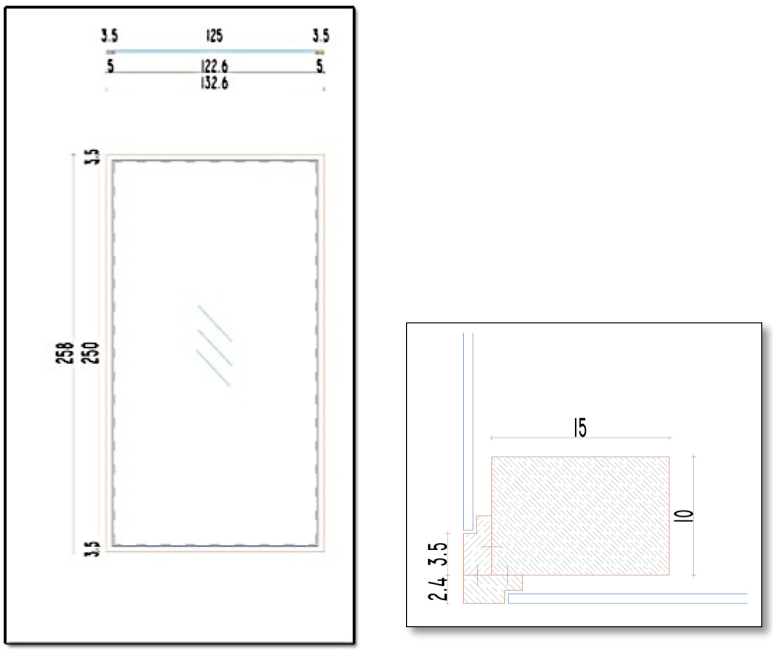


Figure 4.3 : One panel (left) and combination detail of panels (right).

One panel is assembled to be used as a door. Timber frame is also used in this project, like traditional timber frame construction. Each panel is fixed to the timber posts (10x15cm) **(4.3)**. The vertical forces are designed to be fully taken by the timber posts in order to avoid shear in more than one direction on the bondline. Moreover, timber beams are connected the timber posts for carrying timber and glass roof.

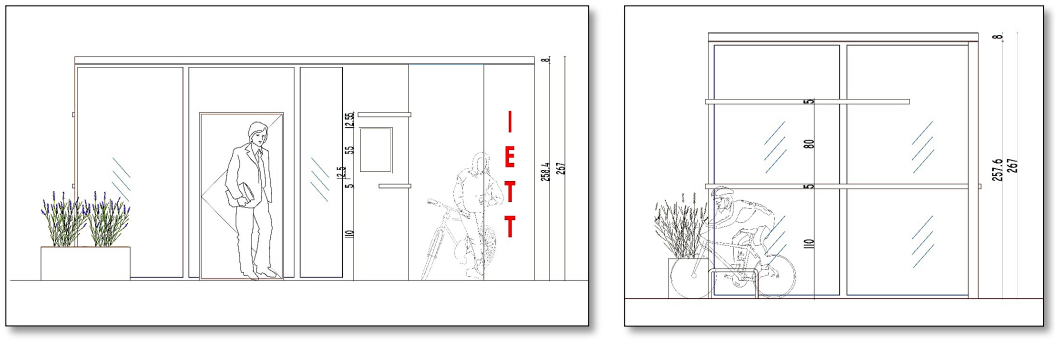


Figure 4.4 : Drawing of front view (left) and side view (right).



Figure 4.5 : Front view (left) and side view (right).

Timber slats are used in facades for visual. Timber-glass roof is extanded for protect users which are waiting outside. In addition to, bicycle lock place and flower pots are made with timber **(4.5)**. So they complement the design in a similar way.

After the design, structural accounts were calculated afterwards. Firstly, some loads such as dead load, snow and then compression and absorbtion of wind were determined according to TS 498 (Turkish Earthquake Code and Turkish Loading Code). In the column max stress (σmax) value was found **61,5** kg/cm² according to the results of the load analysis programme SAP2000 which is under the allowable stress (100 kg/cm²).

Several joint details can be applied for timber beam-to-beam and beam-to-column connections. One of these details is chosen for this pilot project and shown in the Figure **4.6**. The use of smaller side plates can transmit force and allow timber movement.

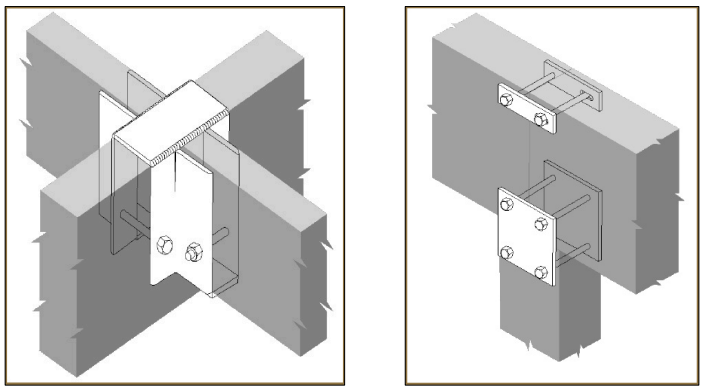


Figure 4.6 : Weld bracket beam-to-beam and smaller side plate used for beam-to-column.

Two different connection details can be chosen for column-to-base (**4.7**).

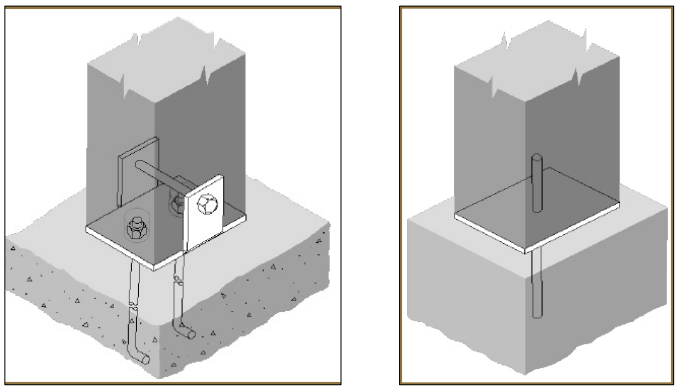


Figure 4.7 : Bearing plate (left) and simple steel dowel (right) for column-to-base.

4.2 Resting Place

The other design project topic is a resting place. For the hexagonal-shape platform that is located in ITU-Faculty of Architecture campus, four different concepts of resting place for academic members are designed. The site has a beautiful view of surrounding landscape and total area of the platform is nearly 65 m^2 **(4.8)**. Three concept project are designed for this place.

The first design consists of different sections combination of timber. It expands and shrinks as the accordion **(4.9)**.



Figure 4.8 : Hexagon place in ITU-Faculty of Architecture campus.

Timber seatings which are located in the middle of the timber section, are the similar forms **(4.10)**.

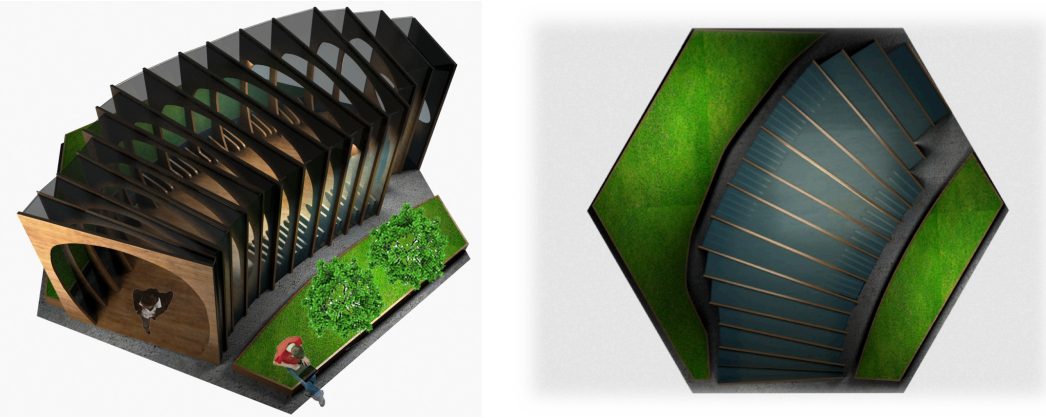


Figure 4.9 : Perspective view (left) and top view (right).

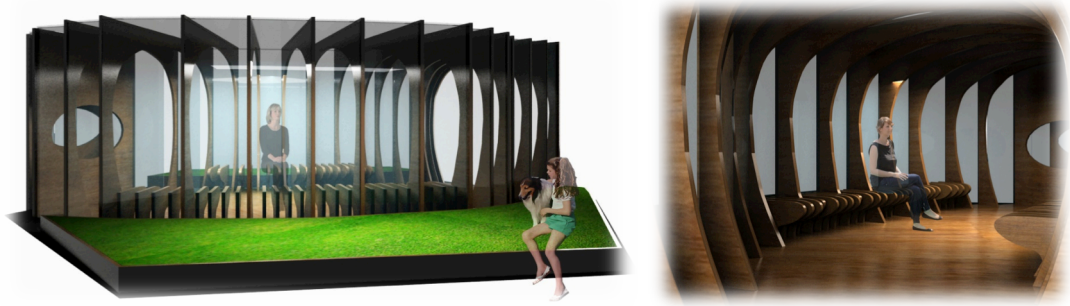


Figure 4.10 : Side view (left) and inside view (right).

The second design concept for resting place consists of nine panels of timber-glass shear walls. Its form is rectangular and simple **(4.11).**



Figure 4.11 : Perspective view.

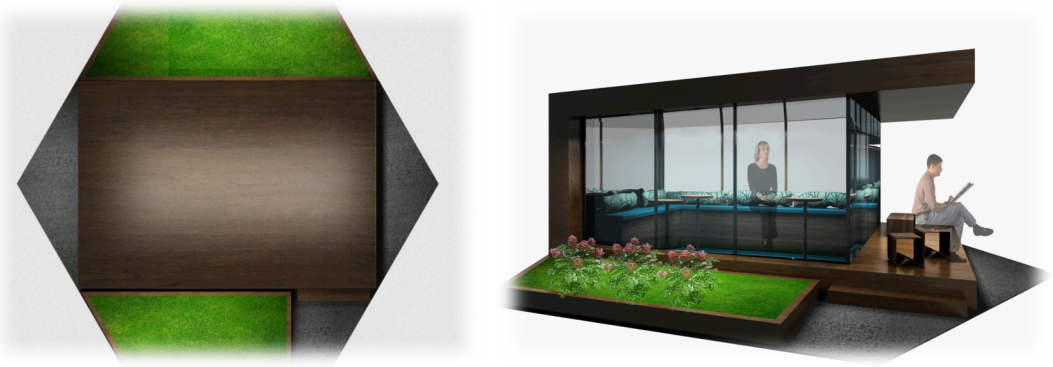


Figure 4.12 : Top view (left) and side view (right).

The third design concept for the same place consists of twenty-four panels of timber-glass shear walls. As Istanbul Technical University`s logo is a bee, the design has been inspired from this logo. The design form is hexagon and some timber-glass shear walls are honeycomb patterned. Its roof is designed with glass, to bring daylight and transparency to the space. Timber-glass shear walls are designed with different patterns for architectural design **(4.13).**

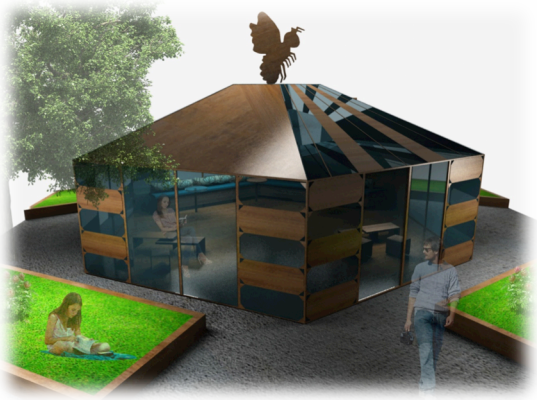


Figure 4.13 : Perspective view.

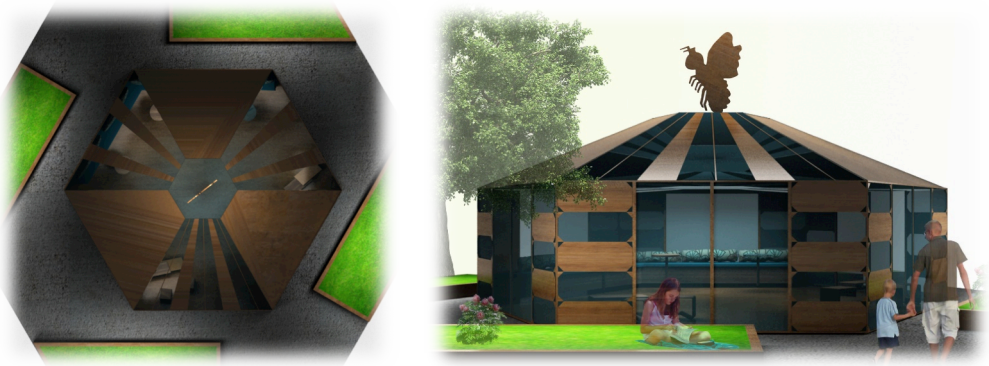


Figure 4.14 : Top view (left) and side view (right).

4.3 Bagel Kiosk

This kiosk is designed to sell bagels. The design consists of five panels of timber-glass shear walls and some timber slats for visual design. Some finishing products like timber table which compatible to the design are used **(4.15)**. This ecological and transparent design can be used at any square of the city.



Figure 4.15 : Perspective view (left) and side view (right).

4.4 Soldier Cabin

The other design project topic is a soldier cabin. This cabin are used for protecting soldiers from bad weather conditions when they are standing guard in front of Dolmabahce Palace. The design consists of four panels of timber-glass shear walls **(4.16).**



Figure 4.16 : Dolmabahce Palace gate (left) and perspective view (right).

4.5 Result of Pilot Projects

Timber-glass composite structural elements combine the advantages of both materials. It provides warmth to the structure with using timber and transparency with using glass. Combining glass with the ductile material timber improves the structural performance after failure and expands the scope of applications beyond the initial limits. It is an important advantage of glass-timber composites that manufacturing of these structural elements doesn`t demand heavy industrial facilities. On the contrary, these composite elements are produced by fast and low power consuming techniques. The suitability of glass-timber composites to ecological structures also empowers the value of these systems. Furthermore, those composite elements enable a more efficient functionality of structural glass elements by allowing the use of approved timber joining techniques. The results provide a marketable component system for buildings that optimally uses timber and glass. Timber-glass component as an ecological and sustainable building material has a lot of advantages to be discovered. These pilot projects presented load-bearing timber-glass composite elements as an appealing alternative structural systems in architecture as well.

5. MARKET SURVEY

This chapter presents market survey with timber and glass industries and their results. Market survey is aimed to introduce the new timber-glass composite structural elements which developed in project and cooperation with timber and glass industries to take it part amongst other structural systems. In order to help this aim and identify overall tendency, timber industry is contacted with survey and the timber and glass surveys are represented diagrammatically. Besides that, comments of the these industry firms are indicated.

5.1 Timber Market Survey

Timber Market Survey provides information on timber and timber products and usage of timber material as load-bearing systems in Turkey. Firstly, twelve questions which were asked to timber firms in timber structure fair and their response are given below diagrammatically.

1. What is your first impression about the usage of timber-glass composite as load-bearing system? What do you think?

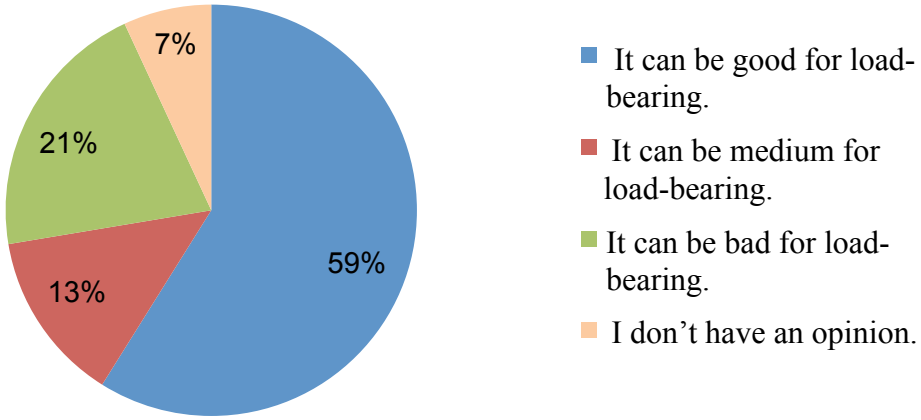


Figure 5.1 : Graphical result of the first question of timber survey

Timber industry have thought substantially that timber-glass composite structural material could be good as load bearing. Some firms have thought that load bearing could be poor by considering that timber material is flexible and the raw material of glass is rigid **(5.1)**.

2. Nowadays, what is timber material used mostly as?

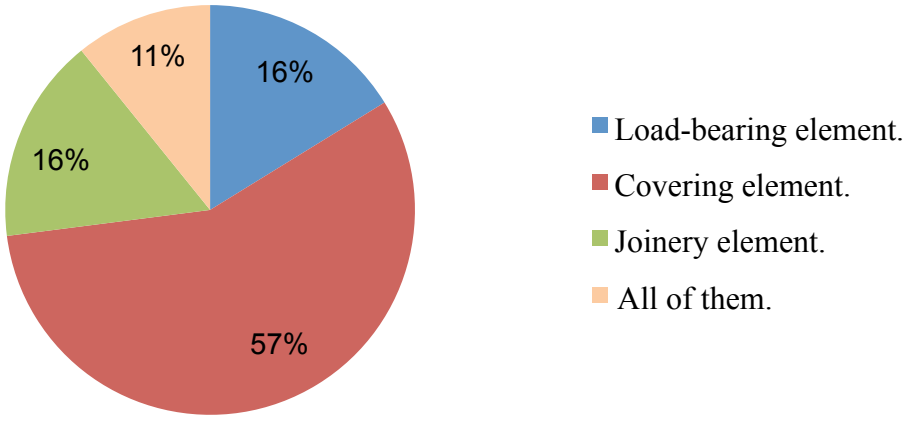


Figure 5.2 : Graphical result of the second question of timber survey

Timber is used as flooring, roofing, ceiling, inner and exterior covering in structures, considered as covering materials. It is equally seen that timber is used as load bearing element like column and beam and as joinery element like door, window and decoration products **(5.2)**.

3. Which type of tree is more resistant as load-bearing material?

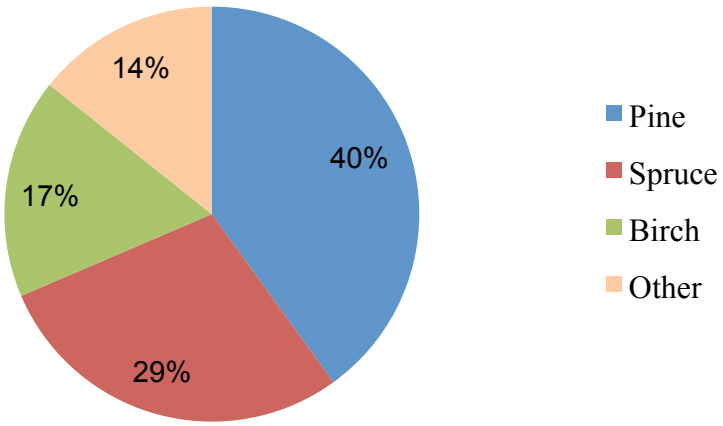


Figure 5.3 : Graphical result of the third question of timber survey

Types of timber used in structures are separated into two groups, coniferous (softwoods) and broad-leaved (hardwoods). Timber industry have suggested pine tree as a coniferous tree mostly used in structure applications. Pine grows almost everywhere in Turkey. Another softwood, spruce tree is located in 2nd place for structure usage by easy-process. It is indicated that plywood obtained from a birch tree as hardwood, has a high strength. Another hardwood, oak tree is preferred to be used in load bearing system for its solid structure and high strength. Iroko tree is suggested to be used in structure by its high strength against natural rotting, insects and moisture. It is a high-cost tree. Besides that, a lot of firms indicates that teak tree has a high strength but low usage in load bearing system **(5.3)**.

4. Considering the chemical and physical characteristics of timber material, if it is combined with glass, how resistant would that be?

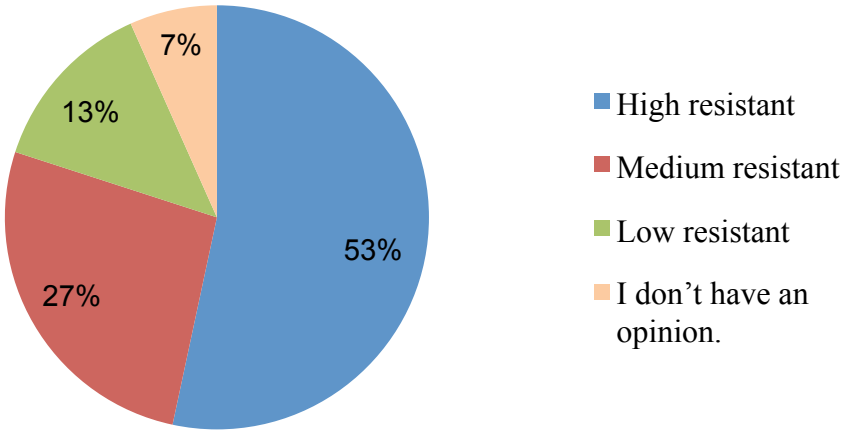


Figure 5.4 : Graphical result of the 4th question of timber survey

It has been considered by timber industry that it can be a high-strength structural component if movement of timber can be controlled and the torsion and strain of glass can be prevented. Some firms indicate that timber is the load bearing element whereas the glass is the loaded element **(5.4)**.

5. When timber is used in load-bearing system, is it necessary to preserve timber? If it is, what method can be performed?

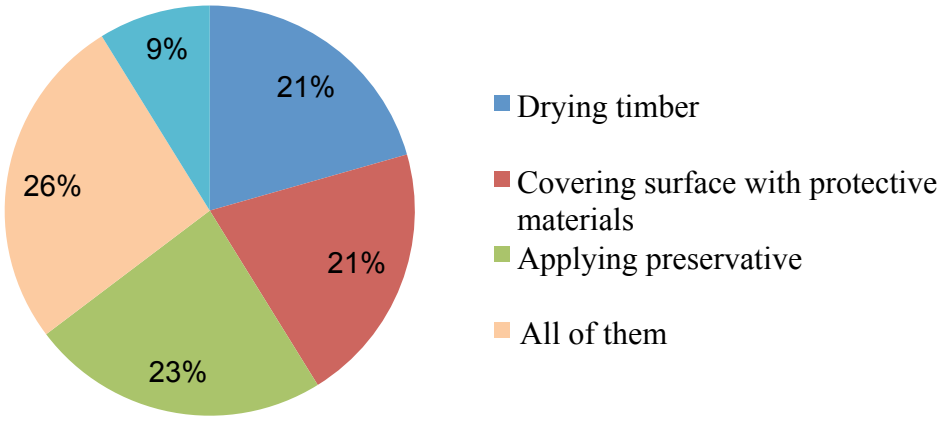


Figure 5.5 : Graphical result of the 5th question of timber survey

Timber industry have indicated that preservative methods can be applied sometimes together and sometimes one by one for extend the lifetime for the strength of timber. Timber drying is very important, especially to protect timber against insects and fungus. Surface protection can be applied preferably. Preservative material can be applied for fire detainment. Other methods are thermal process and resin removal. Some firms indicate that it is not necessary to apply preservatives to very high quality product **(5.5)**.

6. In our research named "Application of Load Bearing Timber-Glass Composite Structural Elements in Load Bearing System of Building", plywood is used. What do you think about the strength of plywood as a load-bearing material?

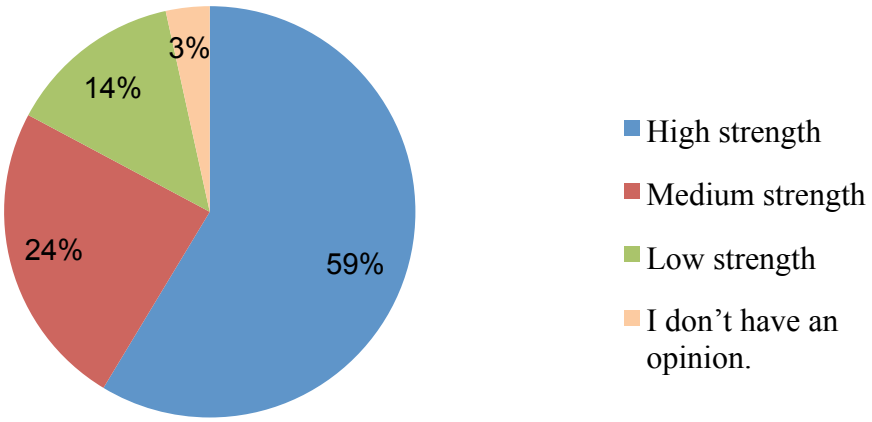


Figure 5.6 : Graphical result of the 6th question of timber survey

Timber industry have indicated that plywood has a higher strength than solid timber material does because plywood is a product laminated as cross and long-grain. Some firms have thought that plywood, which is structural timber panel, can be favored by firms because of its strength **(5.6)**.

7. As a solution for housing problem, how proper do you think timber-glass composite material is?

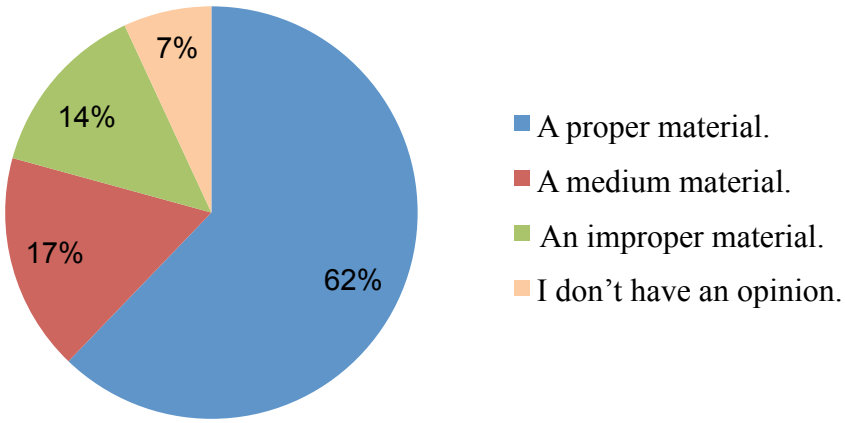


Figure 5.7 : Graphical result of the 7th question of timber survey

Timber firms have indicated that timber-glass composite structural element is very proper for usage in housing, however they emphasized that it should be tested further **(5.7)**.

8. Besides of housing, what kinds of building do you think this material is a good choice for? (Multiple options can be marked).

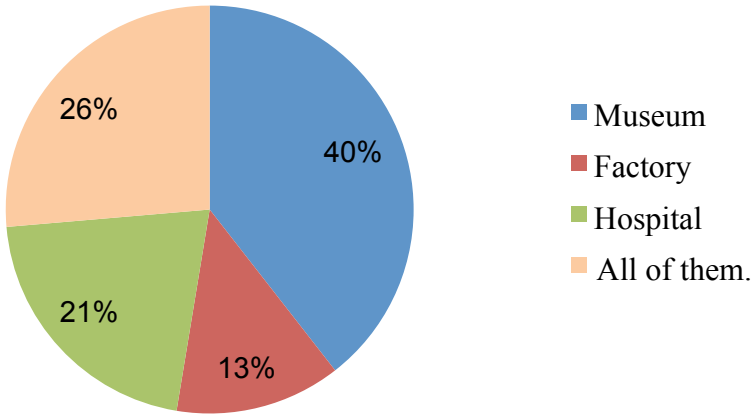


Figure 5.8 : Graphical result of the 8th question of timber survey

Timber firms recommend that this structural element, which is produced by combining timber, an ecological material with glass, should be used almost everywhere. Besides the indicated building, the usage in structures such as school, villa-type residence, gym, workshop, office, administrative building and dormitory is also recommended **(5.8)**.

9. Do you think that this new structure element will be used in Turkey and can be competitive with alternative structure elements?

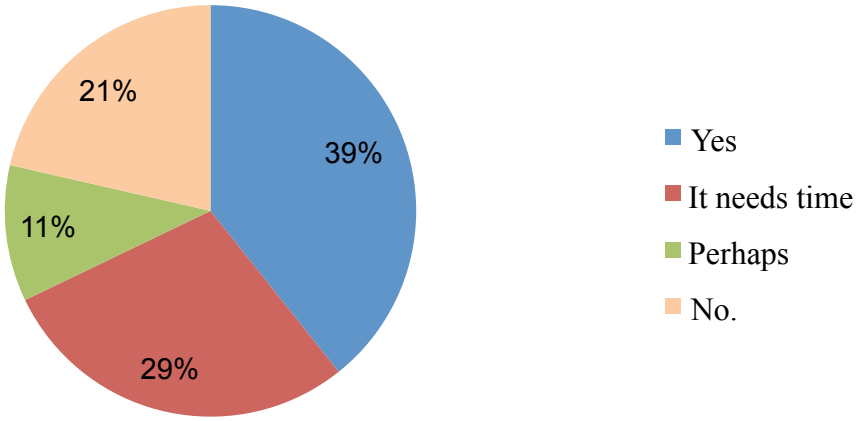


Figure 5.9 : Graphical result of the 9th question of timber survey

Timber firms have supported the idea of that, this new structural element will be used in Turkey and will compete with other structural elements. Some firms have indicated that timber will not compete with other products since it requires maintenance and high cost. Moreover it will be preferred in exclusive projects and projects that have aesthetic concerns **(5.9)**.

10. If your firm manufacture the plywood, according to which standards do you perform?

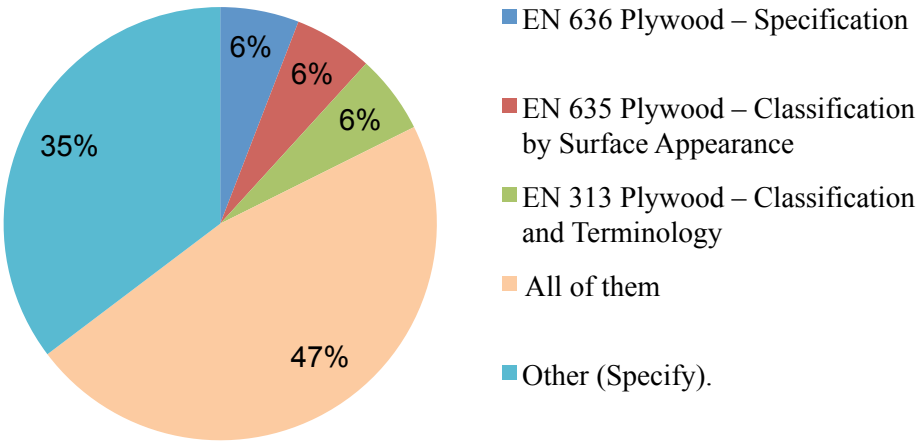


Figure 5.10 : Graphical result of the 10th question of timber survey

Timber firms have used almost all indicated standards. Besides, these standards and certificates are used: EN 1995-1: 2004 'Design of Timber Structures', EN ISO 17225 'Solid biofuels fuel specifications and classes', ASTM D1037 ''Standard Test Method for Evaluating Properties of Wood-Base Fiber and Particle Panel Materials', DIN 1052 'Design of Timber Structures', TS 446 'Coniferous saw logs', BS EN 14080: 2013 'Timber Structures, Glued laminated timber and glued solid timber' and E1 Health Certificate **(5.10)**.

11. If your firm merchandise plywood, how do you obtain plywood mostly, with your manufacture or with imports?

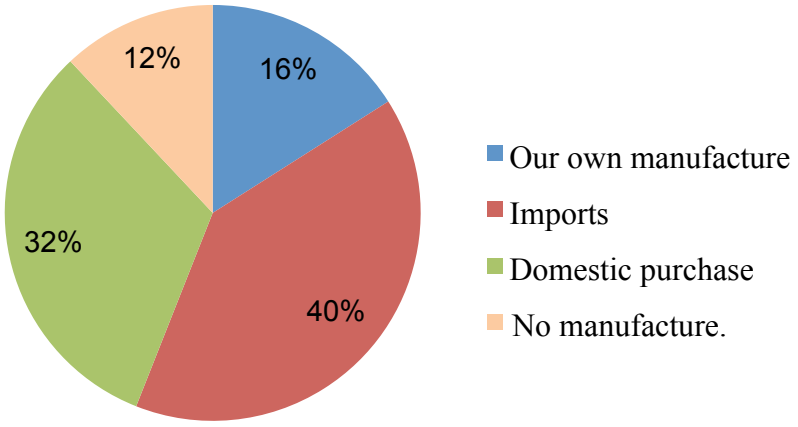


Figure 5.11 : Graphical result of the 11th question of timber survey

Timber firms provide timber material substantially as imports. Apart from that, many firms provide the raw material from the local firms and develop the product **(5.11)**.

12. Prototypes of this new structure element are essential to release and to research in order to make it a safer element. Would you support the research, considering this process?

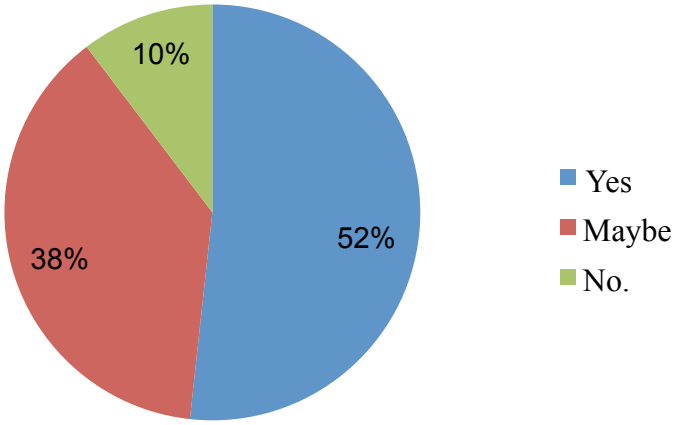


Figure 5.12 : Graphical result of the 12th question of timber survey

This new structural element is considered to be supported substantially by timber industry. Some firms have not supported the product by considering that glass material is fragile **(5.12)**.

5.2 Glass Market Survey

Glass Market Survey provides information on glass and type of glass and usage and manufacture of glass material in Turkey. Twelve questions which were asked to glass firms and their response are given below diagrammatically.

1. What is your first impression about the usage of timber-glass composite as load-bearing system? What do you think?

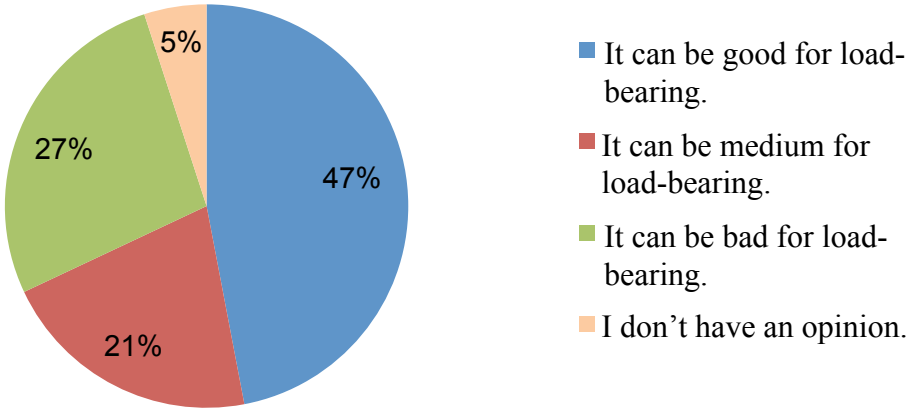


Figure 5.13 : Graphical result of the first question of glass survey

Firms mostly agree that the use of load-bearing timber-glass composite structure element could be good. Some firms indicate that the reason of this is based on the strength of silicone adhesive which combine timber and glass. The strength of adhesive also affects the system positively. The firms, which supports that this system could have a weak load-bearing, due to its fragile structure and vulnerability to impacts **(5.13)**.

2. Nowadays, what is glass material used mostly as?

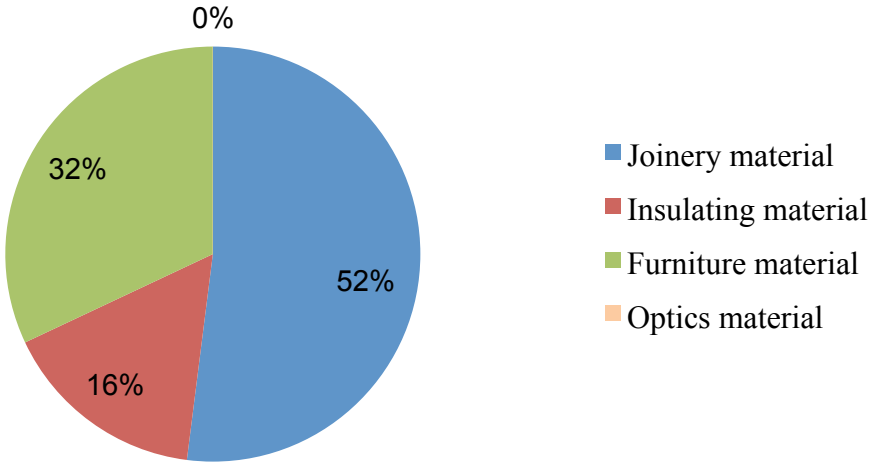


Figure 5.14 : Graphical result of the second question of glass survey

At the present time, glass material is mostly used in timber work (window, door, balcony and balustrade). Many firms indicate that glass is used with exterior structure as timber work material. They think that glass used as building material is

also used greatly in automotive industry. Besides that, glass is also used in furniture insulation and optics **(5.14)**.

3. Which type of glass is more durable as structural material?

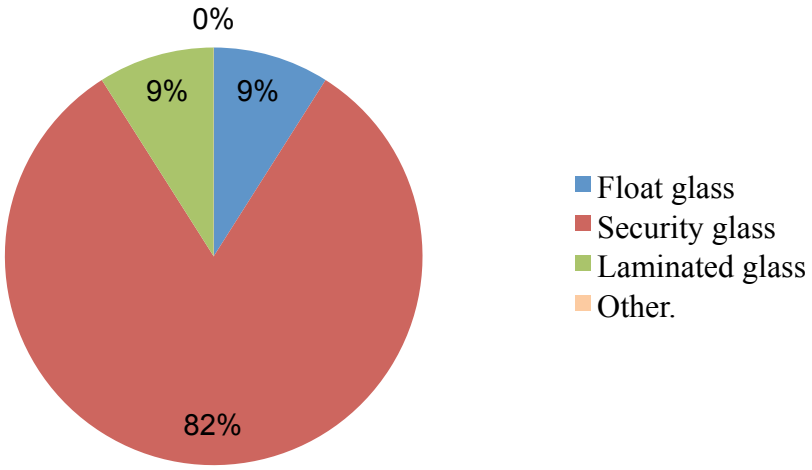


Figure 5.15 : Graphical result of the third question of glass survey

Glass is a frangible material and standard flat glass has a weak strength to impacts. In order to enhance the strength to impacts, it is required to improve glass with safety properties through secondary processes. Hence the tempered and laminated glasses known as security (safety) glass are indicated as highest-strength glass. Many firms also indicate that the strength can be improved by enhancing the width of glass **(5.15)**.

4. Considering the chemical and physical characteristics of glass material, if it is combined with timber, how durable would that be?

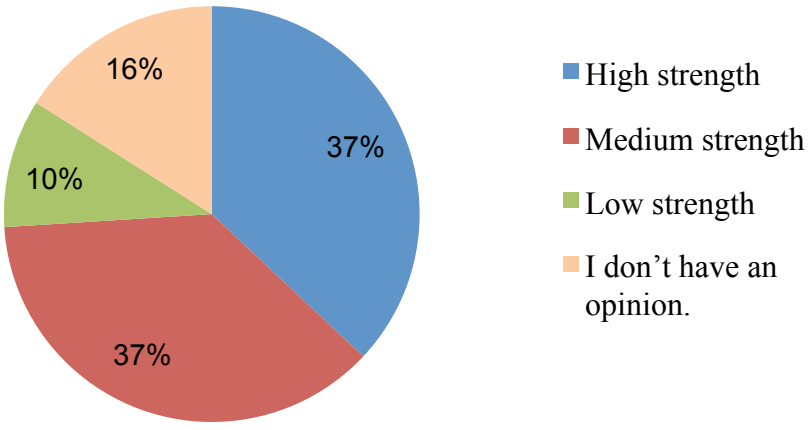


Figure 5.16 : Graphical result of the 4th question of glass survey

Many firms indicate that the strength can be good when stiff glass combines with timber which has a fine flexibility. Some firms declare that this system doesn't have a strength as good as metal structure material does. Besides that, it is indicated that the strength can vary through the dimension of material and its field of use **(5.16)**.

5. When glass is used in load-bearing system, what can be done to strenghten glass as a precaution to possible threads?

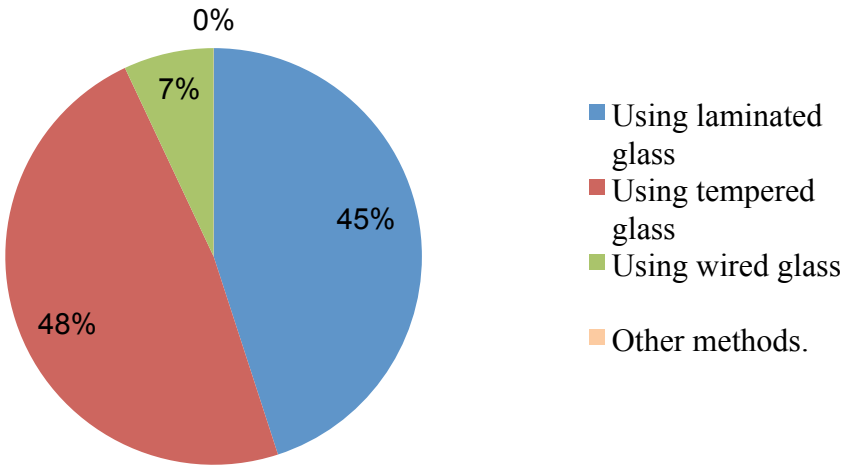


Figure 5.17 : Graphical result of the 5th question of glass survey

Many firms indicate that lamination and tempering methods are commonly used to reinforce the glass. These methods reduce the risks of injury as it retains the pieces during instant of failure. Additionally, merely less firms indicate that high durability to dangers is provided by wired glass, which is produced as wire webs are pressed into hot glass **(5.17)**.

6. In our research named "Application of Timber-Glass Composite Structural Components in Structure-Bearing System", tempered glass is used. What do you think about the strenght of tempered glass as a load-bearing material?

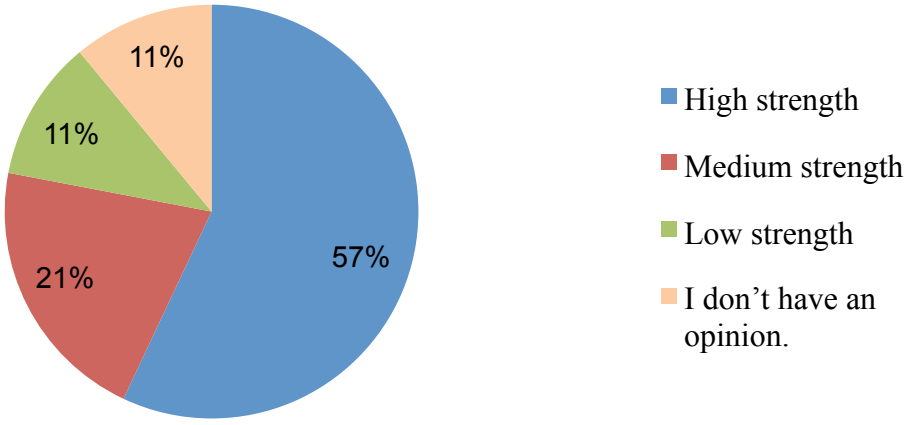


Figure 5.18 : Graphical result of the 6th question of glass survey

Firms think that tempered glass has a higher strength in load-bearing system. It is also indicated that it should be tested with the load which will be exposed. It is mentioned that the strength is increased five times much as glass is tempered. It is stated that tempered glass can be used as load-bearing element when it is laminated twice or more through polyvinyl butyral (PVB) layers **(5.18)**.

7. As a solution for housing problem, how proper do you think timber glass composite element is?

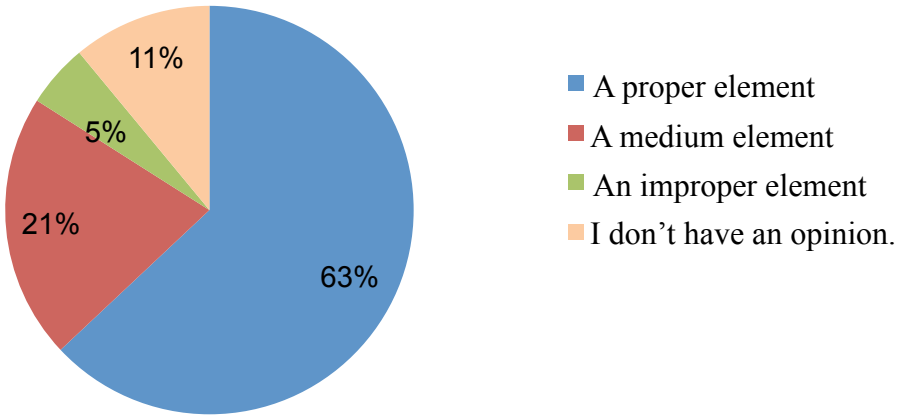


Figure 5.19 : Graphical result of the 7th question of glass survey

It is highly supported to use timber-glass composite structure element in housing. Some firms indicate that this system should be used in two-story structures instead of high structures and it can be expensive **(5.19)**.

13. Besides of housing, what kinds of building do you think this material is a good choice for? (Multiple options can be marked).

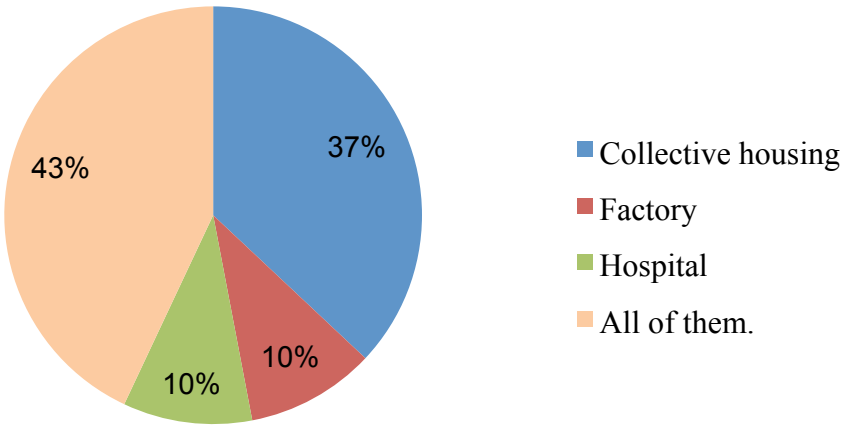


Figure 5.20 : Graphical result of the 8th question of glass survey

It is indicated that timber-glass composite structure element is also a proper material besides in housing and can be used in collective (mass) housing, business center, hotel, mall, cafe, restaurant and greenhouse **(5.20)**.

8. Do you think that this new structure element will be used in Turkey and can be competitive with alternative structure elements?

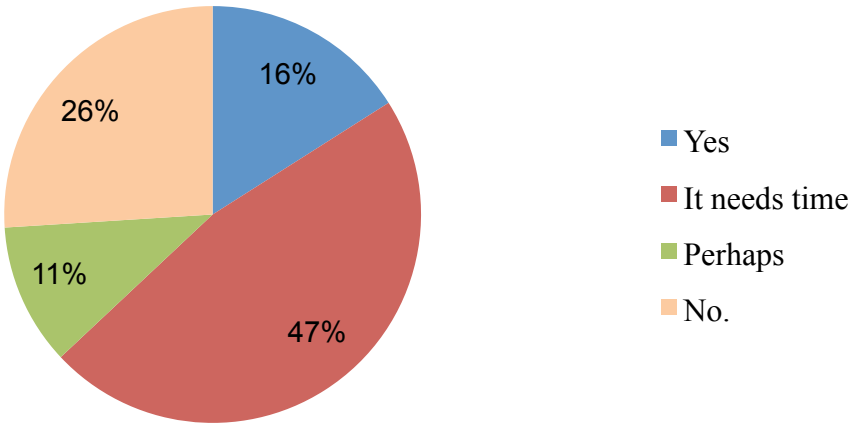


Figure 5.21 : Graphical result of the 9th question of glass survey

Many firms indicate that this new structure element needs time to compete with alternative structure elements in Turkey. It is also concerned that it can be integrated with other structure elements **(5.21)**.

9. If your firm manufacture tempered glass, how do you obtain tempered glass mostly, with your manufacture or with imports?

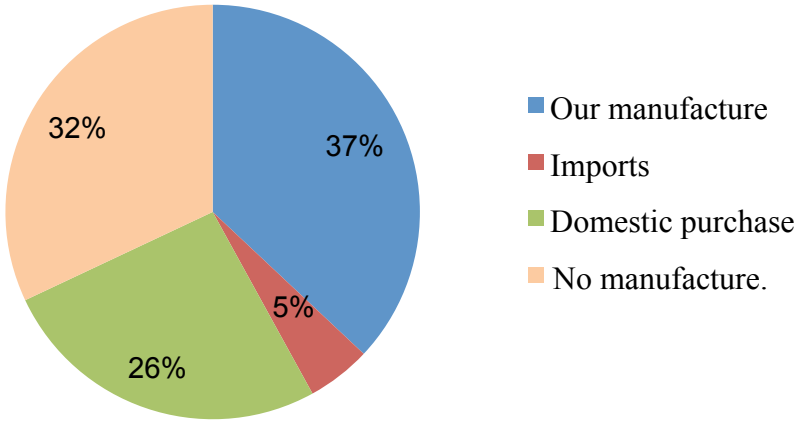


Figure 5.22 : Graphical result of the 10th question of glass survey

There are only two firms in Turkey that manufacture glass as raw material. Many firms purchase glass material from these firms and sell it after their own processes. There are also some firms importing glass **(5.22)**.

10. If your firm manufacture tempered glass, according to which standards do you perform?

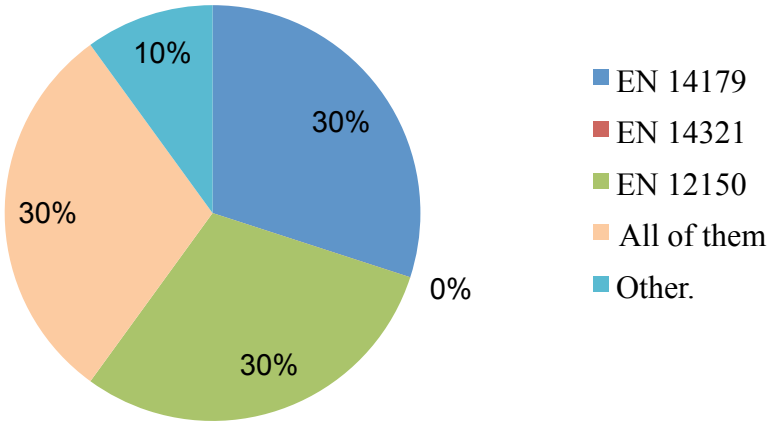


Figure 5.23 : Graphical result of the 11th question of glass survey

Many firms apply almost all of these standards to glass. There are also some firms that manufacture tempered glass through the standard, EN 1863 “Glass in building. Heat strengthened soda lime silicate glass definition and description” **(5.23)**.

11. Prototypes of this new structure element are essential to release and to research in order to make it a safer element. Would you support the research, considering this process?

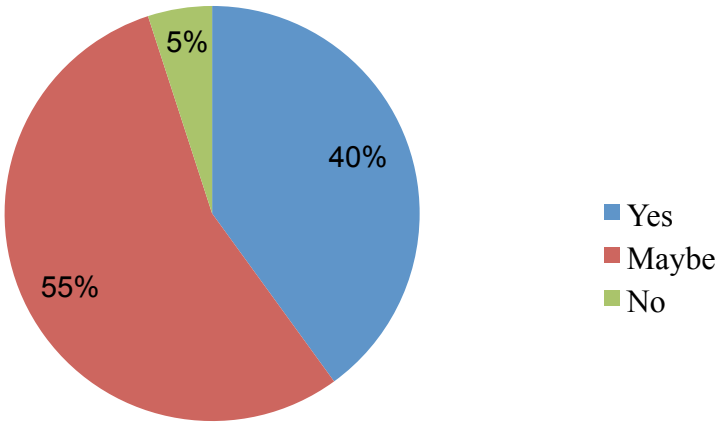


Figure 5.24 : Graphical result of the 12th question of glass survey

Glass firms indicate that they can support the use of this new structural elemenst and the researches on this subject **(5.24)**.

5.3 Results of Market Survey

Timber industry have thought substantially that timber-glass composite structural material could be good as load bearing. Timber material is mostly used as covering material in structures and mostly provided as imports in Turkey. Timber industry have suggested pine tree as a coniferous tree mostly used in structure applications and it grows in almost everywhere in Turkey. Timber-glass composite material is considered to be a structural element with high strength if the negative sides of glass are prevented. Timber industry have indicated that, preservative methods such as timber drying, surface covering with preservatives and preservative injection can be applied sometimes together and sometimes one by one to improve the lifetime and the strength of timber. Timber firms have indicated that plywood has a high strength and is used in structures and many other areas. These firms mostly support the idea

of that, timber-glass composite structural element will be used in Turkey and will compete with alternative structural elements.

Glass firms mostly suppose that the timber-glass composite structural element could be good for load-bearing element. Glass material is mostly used in structures as timber work material. Glass firms in Turkey purchase glass material from two manufacturer firms and sell it after their own processes. These firms indicate that tempered and laminated glasses known as safety glasses are mostly preferred and lamination and tempering methods are effective on glass enhancement. Glass firms indicate that tempered has a high strength and can be used in many places besides housing. Glass firms mostly support that new timber-glass structural element can be used in Turkey and can compete with alternative structural elements in the course of time.

6. CONCLUSIONS

More knowledge about timber-glass and adhesives which combining these two materials were obtained by processing experimental and theoretical studies about timber and glass composite load-bearing elements, which our country are unfamiliar with, for those to be used more commonly and safely.

The behavior of timber-glass composite structural elements were analyzed with experimental studies under monotonic and cyclic loadings. According to experiments, it is observed that timber glass composite shear wall has a higher rate of rigidity under monotonic loading. But, it should be pointed out that cyclic loading pattern is a more realistic approach than monotonic loading for simulating lateral loads, such as earthquake and wind loads.

The behavior of timber-glass composite structural elements were also analyzed with experimental studies under long term loadings at exterior conditions with different loading levels. It is clearly seen that the shear walls with the lower load level suffer less creep deformation than those with the higher load level. The specimens which are located in different direction and exposed to different climatic influences (such as wind, daylight angles) , thereby it is observed that these specimens have different vertical displacement.

It is also observed that structural glass elements have more efficient functionality by allowing the use of timber and timber joinery techniques. Combining glass with the ductile material timber improves the structural performance after failure and expands the scope of applications beyond the initial limits.

It is expected that load-bearing timber-glass composite elements will be remarkable alternative structure element by means of the support of theoretical studies to experimental results and the suggestions of pilot project application. These pilot projects presented load-bearing timber-glass composite elements as an appealing alternative structural systems in architecture as well.

Market research surveys also support the opinion of that, timber-glass composite structural elements will be able to be used. Timber and glass industry have thought substantially that timber-glass composite structural material could be good as load bearing.

In spite of all-purpose properties and excellent adaptation of this product, and positive results obtained after experiments, it can be an optimistic approach to expect this product to become widespread and well accepted in market immediately. But one of the main objectives of this project is to become a positive structural system for ecological, low-energy structures, which examples can be observed gradually in our country.

One of the expected results is that timber, which is favored for ecological structures, will be used widely in different areas of usage, and glass will be encouraged to be used apart from the use with concrete and steel.

The advantages of using this structural system, concerning the behaviours are: Aesthetic value, near waste-free building design, recyclability of all building elements after service life, lightweight and multifunctional applicable as load bearing. The important one of possible results is to create a high-competitive structural system. Other important advantage of glass-timber composites that manufacturing of these structural elements doesn`t demand heavy industrial facilities. On the contrary, these composite elements are produced by fast and low power consuming techniques.

This marketable component system which is timber based, will be used with the conventional timber construction. It can help increase the use of timber as building material as well as the statically use of glass panes and plates. The bonding system is also very important, because the adhesive brings together strength and flexibility. An appropriate adhesive could provide a uniform stress distribution at the transition between the materials. Regarding the analysed adhesives, silicone is the most advisable for timber glass composites, as it allows greater indexes of flexibility, thus assuring the needed structural mechanical resistance and load distribution ability. Summing up, it is possible to state that, with this bonding technology, the mechanical capacity of the composite system is substantially higher than the sum of the

individual behaviours of the composing materials, which confirms its structural capacity.

This new composite structural system will be used in several areas, such as winter houses, exterior elements, prefabricated houses, greenhouses, office buildings, schools and kindergartens, elevator shafts, small objects, transparent indoor wall applications or structures that are constructed to protect historical buildings against environmental effects.

The unique combination of timber products with glass material will also deeper investigations regarding the interfaces, the compatibilty and the collaboration between the different materials. The final issue consists in optimizing composite system by using the best characteristics of each material with the aim to develop and advance a high competitive composite building systems.

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