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Examination of Material Selection's Effect on Lighweightness on Structures

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Abstract

This article encompasses an investigation through the scanning of existing research and structures in the literature, focusing on the influence of material selection on the lightweight nature of the structure. Materials such as paper-cardboard, carbon fiber, wood, ETFE-PTFE, and FRP, along with 53 structures made from these materials, were examined in the context of structural lightness as studied in the literature. In structures produced using these materials and robotic fabrication methods, the effects of the fabrication method on structural lightness were investigated. As a result of the selected materials and systems, various advantages are provided, including structural lightness, reduced damage and deterioration from lateral forces such as earthquakes due to mass reduction, portability, reconfigurability, cost-effectiveness, structural efficiency, and the benefit of rapid installation. While examining structures produced from materials that enhance lightness, the potential negative effects of lightness on the structure were also considered. The findings from this analysis reveal that the lightweight nature of certain material choices affects structural configuration, connections, and subsystems.This study aims to contribute to the literature in the context of the structure-lightweight relationship and aims to serve as a compilation for subsequent research endeavors.

Keywords: *Lightweight structure, structural efficiency, paper and cardboard material, carbonfiber material, robotic fabrication.*

Malzeme Seçiminin Yapıların Hafifliğine Etkisinin İncelenmesi

Öz

Bu makale, literatürdeki mevcut araştırma ve yapıların taranması yoluyla, malzeme seçiminin yapının hafif doğası üzerindeki etkisine odaklanan bir incelemeyi kapsamaktadır. Yapının hafiflemesi üzerine literatürde çalışma yapılan malzemeler olarak kağıt-karton, karbonfiber, ahşap, ETFE-PTFE, FRP malzemeleri ve bu malzemelerden üretilen 53 yapı incelenmiştir. Bu malzemeler ile üretilen ve yöntemsel olarak robotik fabrikasyon kullanılan yapılardaysa bu yöntemin yapıya hafiflik kapsamında etkileri araştırılmıştır.Seçilen malzeme ve sistem neticesinde yapının hafif olması, kütle azalmasına bağlı olarak deprem gibi yanal kuvvetlerden kaynaklanan hasar ve bozulmaların azalması, taşınabilirlik, yeniden yapılandırılabilirlik, maliyet etkinliği, strüktürel etkinlik ve hızlı kurulum faydası gibi çeşitli avantajlar sağlanmaktadır. Hafifliğe katkı sağlayan malzemeler ile üretilen yapılar incelenirken, avantajlarına ek olarak hafifliğin yapıya olumsuz etki yapıp yapmadığı da incelenmiştir. Çeşitli malzeme seçimlerinin hafiflik yönünün, yapısal konfigürasyona, yapısal bağlantılara ve yapısal alt sistemlere etkisi olduğu yapıların incelemesi sonucunda elde edilen bulgulardandır.Bu çalışma, hafif strüktür, yapı-hafiflik ilişkisi bağlamında literatüre katkı sağlamayı ve daha sonraki araştırmalara derleme niteliği taşımayı amaçlamaktadır.

Anahtar kelimeler: *Hafif strüktür, strüktürel etkinlik, kağıt ve karton malzeme, karbonfiber malzeme, robotik fabrikasyon.*

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1. Introduction

Resource management and sustainability are considered important when dealing with limited resources in today's world where the construction industry occupies a large share.The effective use of the material is directly related to its quantity. Designing the existing effect with fewer materials ensures an effective design, reduces the total load, and as a result provides economy in construction. Creating the same strength with a hollow section rather than creating a fully filled section is one of the methods of providing lightness (Figure 1).

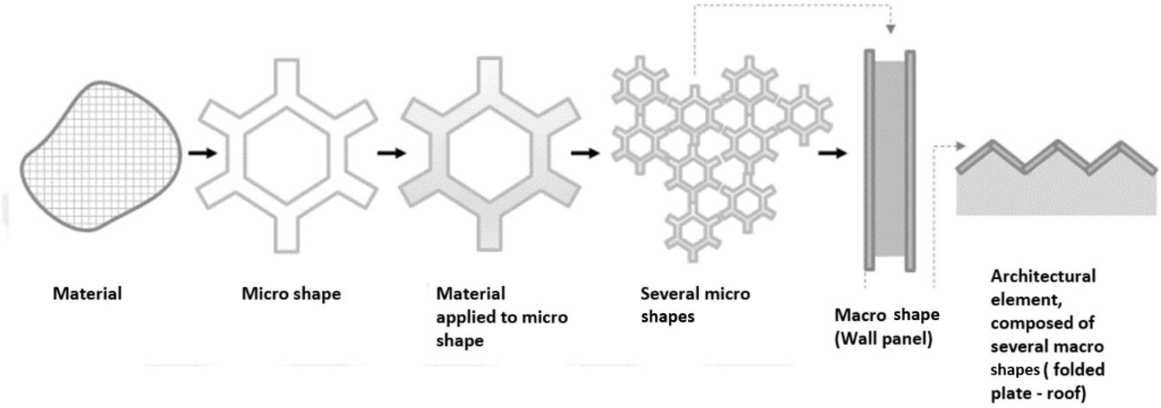


Figure 1. The fact that the material forms the general structure with a hollow form instead of a solid section ensures the lightening of the unit (Adapted from Ashby, 1999).

The lightening with the decrease of the transferred loads also affects the dimensions of the other parts related to the structure and can contribute to the lightening of the system as a whole. In the studies, it is seen that the fact that the facade element is made of light material affects the structure, especially the dimensions of the profiles that carry it, up to the dimensions of the foundation that will serve the load transmission principle. Lightness also provides portability to the structure. The structure's composition of unit elements, its disassembly and reassembly/assembly features support transportability. The lightness of the materials and units also provides the ability to be carried by people. The lightness of the units affords an advantage such as ease of operation and reduction of necessary equipment for operation (Menges, Dörstelmann, Knippers & Auer, 2016).

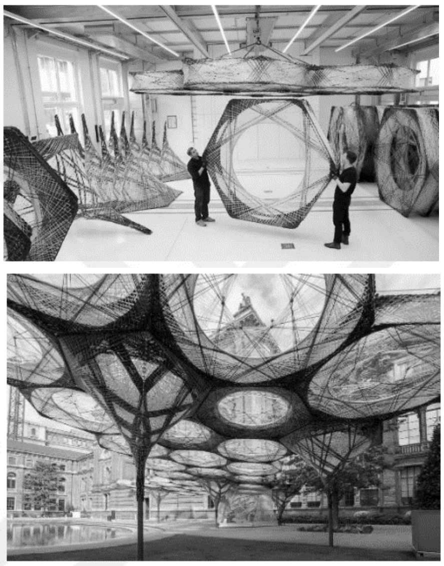


Figure 2. ICD/ITKE Elytra filament pavilion, one unit light enough to be carried by 2 people, (Institute for Computational Design. (n.d.). *Elytra filament pavilion)*

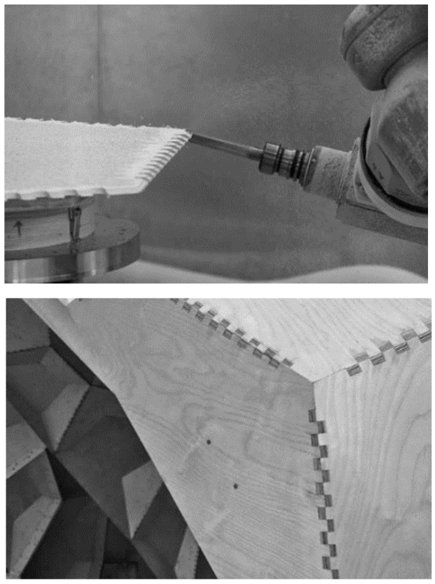


Figure 3. The shell structure, which is combined with the formation of finger joints, does not require any additional material in the joint, providing a lightness brought by the shape, (Krieg, 2011)

In this study, the effects of lightness in the structure were investigated by following the current state of material technology and the studies carried out (ETH Zurich UHPC), experimental university pavilion studies (Figure 2), field studies and researches on a certain lightweight material, such as paper Form and the way the pieces come together are another two of the important supporting factors in making the most impact achievable with the least. It is seen from the examples that robotic fabrication systems are used to create complex forms and ways of coming together with informatics with current technology (Figure 3). It is seen that the entire structure becomes lighter in such structures that do not require new elements in the connections and are built with light materials. With such methods, it is seen that for a certain size scale in the process, it simplifies, economizes and reduces the number of required personnel from the unit element to its installation (Latka, 2017). This study is shaped around the question of how to achieve the maximum effect with the least material. It aims to contribute to the literature by explaining how this problem is done with current materials and to investigate its effects by establishing a relationship with lightness through building examples. The lightness, which can be achieved in many ways, such as thinning the section with geometry, designing the section filled with geometry as hollow, designing the additional joint so that no other material is required, choosing the material with high strength but low density, will be examined through structures using different material groups and the results will be discussed.

2. Material and Method

In this study, sample structures built with 5 selected lightweight building materials in which total of 53 buildings from these five categories were examined. The evaluation question set shown in the Table 1 includes information about the structure in different categories such as numerical data, physical criterion-lightness, compliance with environmental conditions and adaptation to Growth/Proliferation conditions. At numeritical data section, a unit weight (kg/m^2) value of the building was tried to be reached by collecting/taking into account the stated kg and total m^2 data of the buildings (if given). In addition, a question set was created to investigate the structure. Apart from the numerical data of the building, the physical conditions (for example, being collected again, being able to be moved, being able to be divided into parts) were investigated. This information was evaluated as the effects that contribute to the lightness. The structures with the lightest unit weight in each material category were compiled. The life expectancy of the obtained structures, their resistance to atmospheric conditions, the requirement for the foundation of the building and their form of portability (by person or by transport) were investigated. It was also examined if it could provide the strength/support criterion together with the unit weight criterion and not have a negative effect on its lightness.

3.Findings and Discussion

Six different materials and structures using these materials are included in the study. Years of construction are from the oldest, 1966, and the latest, 2021.

3.1. Lightweight Structures Made of Paper and Cardboard Material

In this study, 19 structures were produced from paper and cardboard materials (Figure 4). Structural strength, the structure's resistance to atmospheric conditions, and the elements used at the junction points are the three main elements that must be taken into consideration in order to ensure lightness of the material.

Figure 4. Structures produced with the analyzed paper-cardboard material (Latka, 2017). 1-WUST Pavillion (Archi-Tektura. (n.d.). Projects. Archi-Tektura), 2-Paper House (Shigeru Ban Architects. (n.d.). Paper house (1995, 3-Paper Log House (Azevedo, 2015), 4-Cardboard Cathedral (Cai, 2013), 5-Library of Poet (Shigeru Ban Architects., n.d.). Library of a poet, 1991), 6-Nemunoki Childrens Arts Museum (Shigeru Ban Architects.,1991), 7-Miao School (Latka, 2017), 8-OctatubeDome(Tensinet, n.d.), 9-Paper Arch Dome (Washington, 2012), 10- Cardboard House (Stutchbury,n.d.), 11-Paper Church (Shigeru Ban Architects. (1995), 12- Westbrough Primary School (Katus. (n.d.), 13-Studio Kyoto (Designboom. (2021), 14-Japanese Pavillion (Arquitectura Viva. 2000),15- Apeldoorn Theater (Latka, 2017),16-Wikkelhouse: Modular modern solution) Cottrell & Vermeulen Architects, n.d.),17-Ring Pass Hockey Club (Octatube, 2012). Ring Pass),18-PLY Dome (Latka, 2017)

The questions asked to the structures/buildings can be viewed in Table 1.

Table 1. Question set prepared for the evaluation of lightness of buildings (Boylu, 2022)

Evaluation with Question Set			
Project Information			
	Architect		
	Year of construction		
	Build life		
	Material category		
	Size scale		
	Construction cost		
	Structure function		
Numerical Data			
	Square meter information		
	Span		
	Structural system		
	Shell or material tickness		
	Total weight		
Physical Criterion-Lightness		**(1) Positive**	**(0) Negative**
	Permanence-impermanence	Temporary	Permanent
	Is it possible to transport?	Transportable	Not Transportable
	Is it possible to disassemble/rejoin?	Able	Not Able
	Is it possible for unskilled labor?	Possible	Not Possible
	Number of people required for installation	<5	>5
	Is the unit heavy enough for 2 people to carry?	Yes	No
	Are their combinations with light material? Does is require a heavy material?	No	Yes
	Does it require heavy foundation/ground attachment?	No	Yes
	Is the unit element of the system light?	Yes	No
	Is the system installation overall lightweight?	Yes	No
	Is the embedded energy rating low?	Low	High
Compliance with Environmental Conditions			
	Thermal comfort		
	Light		
	Noise control		
	Resistance to humididty-		

	Athmospheric conditions
Adaptation to Growth/Proliferation Conditions	
	Does it consist of modules?
	What is the reproductibility- growht state?
	What is its adaptibility to different functions?

Paper and cardboard materials are inherently impervious to water. In the structures examined, it is seen that the material is coated with impregnation-like additives to increase its resistance to water. This causes it to be removed from the recyclable feature class. Another way of protection was to insulate the building, which has a cardboard structure, from the external environment by covering it with a linoleum-like cover.In order to provide the structural strength of the material, it has been used in different forms at the element level. These have been in the form of tube elements, multiple layers of material, or folded plates. In experimental structures made with paper and cardboard materials, which are not resistant to moisture together with water, the structure in which the main building very few materials are used in the joints is. The Apeldoorn Theater, which is entirely made of cardboard, including its combinations, has not been used after functioning for 1 week (Latka, 2017).

Table 2. Paper material structures, unit weight comparison, (shown in Figure 5) (Boylu, 2022)

Figure Ref. No.	*Building/ Project Name*	*Building Function*	*Function of Paper in Structure*	*Kg/ m²*	*Result kg/m²*
01	Cardboard House	Residence	Loadbearing Frame	2000kg/32 m²	62.5 kg/m²
02	Wesbrough Primary School	School	Column, roof panel	15000 kg /90 m²	166.6 kg/m²
03	Wikkel House	Residence	Loadbearing frame	3000 kg /30 m²	100 kg/m²
04	Apeldoorn Theatre	Theater	Shell	1500 kg/240 m²	6.25 kg/m²

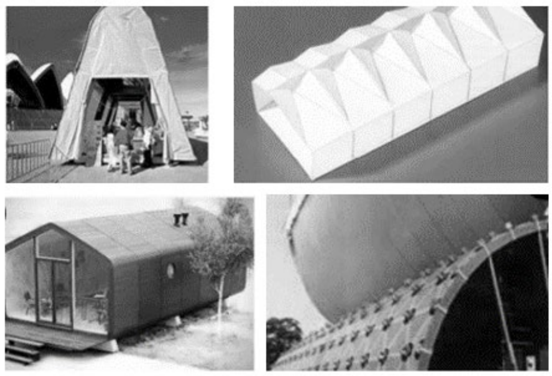


Figure 5. Referance figures for table-1, by order, Cardboard House (Stutchbury, P. (n.d.). Cardboard House) , Westbrough Primary School, (Katus. (n.d.). Wikkelhouse: Modular modern solution) Cottrell & Vermeulen Architects. (n.d.), Apeldoorn Theater (Latka, 2017)

It can be seen in the examples examined that the preferred combination materials for the long-term survival of the building are wood or stainless steel to be more resistant to moisture . The system, which is built from light unit elements such as paper or cardboard, is aimed to be relatively heavier but longer-lasting than the structure made entirely of paper/cardboard. When the structures with unit weight informations are examined, as seen in Table 2, it is seen that the lightest among the structures is the Apeldoorn Theater, which is a temporary, portable structure whose joints are made of paper materials.

3.2. Lightweight Structures with Elements Made of Wood

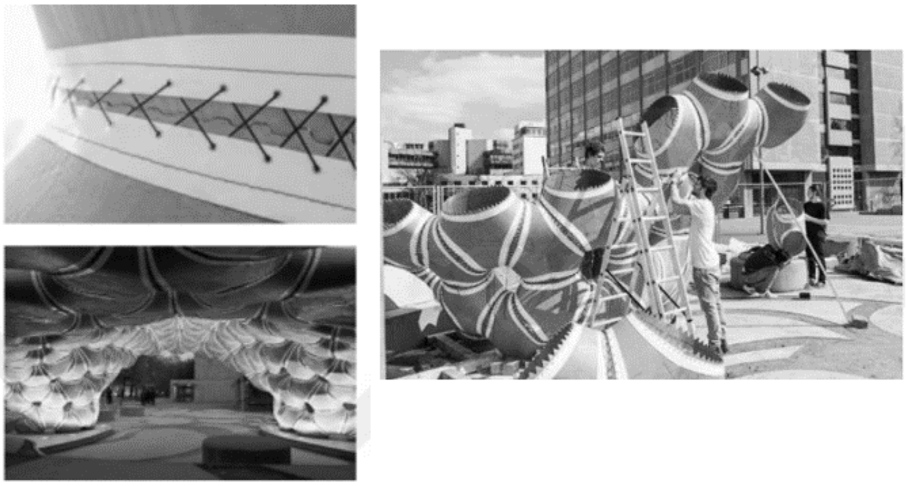


Figure 5. Detailed images of a wooden shell structure (Krieg,n.d.). Elytra Filament Pavilion, Victoria and Albert Museum, Retrieved June 26, 2024)

Within the scope of this study, 11 wooden structures were examined (Figure 5). In the research, examples were examined, especially the experimental pavilion structures made by ICD/ITKE and ETH Zurich. Structures with finger joint that do not require additional material in the joints were found, together with the examples where the wood was sewn very thinly. It can be seen from the examples that arrangements are made regarding the fiber directions in order to increase the strength depending on the thinning of the material, and that the forms that gain strength, such as folded plate are preferred together with the arranged wood materials such as CLT and LVL.

Computer-aided design and robotic fabrication tools were used in the phases of designing the material-effective form, breaking it into pieces, forming and producing the joint details in shell structure formations, which reduced certain items such as required workers and total production time and provided economy (Boylu, 2022).

Table 3. Numbering of structures made of wood and wood types used (Boylu, 2022), 1-Ultralight segmented timber plate Shell(Institute for Computational Design., 2015), 2- Landesgartenschau Exhibition Hall (Parametric Architecture., 2021), 3-SmartShell (MaterialDistrict, 2020), 4-St. Loup Chapel (Birkhäuser., n.d.), 5-Interlocking timber plate Shell (Linden,2017), 6-Vidy Theathre(Yves Weinand Architectes Sàrl + Plus Atelier Cube., 2020), 7-BUGA Pavillion (Institute for Computational Design. (2019)), 8-Sewn Timber Shell (Alvarez, 2017), 9-ITECH, 10-RecyleShell, 11-Portalen Pavillion (Augustynowicz, 2021) and right, material usage by photo referance

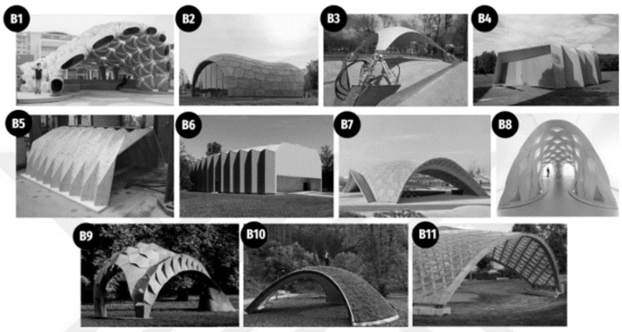


Figure referance number	Wooden Material type
B1	Plywood plate
B2	beech playwood
B3	4mm laminated wood
B4	CLT
B5	LVL-21mm
B6	45mm
B7	-
B8	3.5mm playwood
B9	3mm beech playwood
B10	-
B11	CLT

Stuttgart University's research pavilion structure (Figure 6) is inspired by the sea dollar, with tooth-like recesses in its seams. This plug-in structure of the joints provides a joint area, while additionally the elements are stitched robotically. Thus, a hollow shell structure is formed.While the shape provides strength to the structure, its hollow structure, unit elements, element organizations and combination details provide qualities that reinforce its lightness in many aspects. In the evaluation below (Table 4), it is seen that the structure is the 2nd lightest wooden structure among the structures with weight data.

Table 4. Unit weight values of structures with data produced with wood material (values not given are shown with x), (Boylu, 2022).

Ref. Picture	Building/project name	Kg/m² value	Result value kg/m²
B1	ICD-ITKE 2015-16 pavilion	780kg/85m²	7.85 kg/m²
B2	LAGA pavilion	x/125m²	38.6 kg/m²
B5	Interlocking plate Shell	192kg/25m²	7.68 kg/m²
B7	BUGA pavilion	x/675m²	36 kg/m²

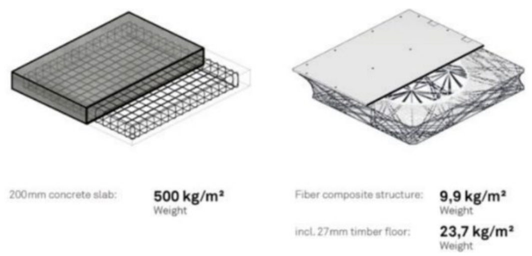
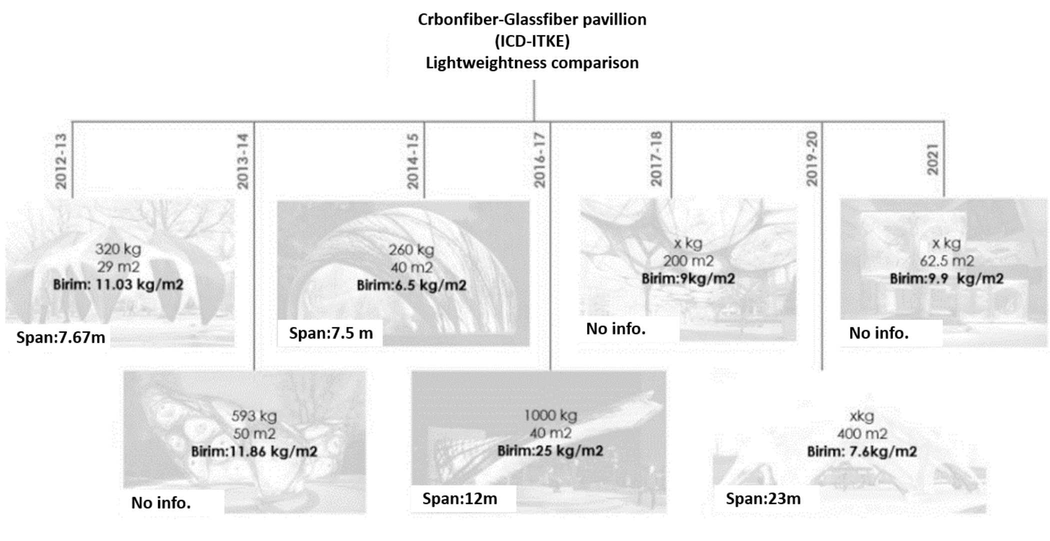


Figure 6. ICD/ITKE 2021 Pavilion, comparison of reinforced concrete slab vs lightweight slab (Menges & Dambrosio, 2021).

3.3. Lightweight Structures with Elements Made of Carbon Fiber, Glass Fiber

In collaboration with ETH Zurich and Stuttgart University, experimentally produced pavilion structures for light structure research, glass fiber and carbon fiber were created using special techniques (such as keeping the fibers in a cold environment - wrapping them in various ways).

Table 5. Weight evaluation of structures made of carbon fiber and glass fiber by years (Boylu, 2022)



These structures were analyzed according to the openings they passed through and according to their weight. It has been observed that there are various forms of cantilevered structures, shell structures or frame structures. According to the unit weight per square meter study, the lightest structure was the 2014-15 pavilion with a unit weight of 6.5 kg/m² (Menges & Knippers, 2015). It is noticed that carbon and glass fiber are used together in the pavilion structures built. The reason why both glass fiber and carbon fiber filaments are used together in structures is the nature of the material as well as the lightness of the material. Carbon fiber is a pure compression material, while glass fiber is a tensile material. The structures were inspired by many natural elements such as lobster shells, the structure of the sea dollar, the behavior of water spiders and the behavior of leafworms, in the name of materials and methods. In the 2012-13 pavilion, which was built by taking the lobster shells as an example, more carbon fiber was wrapped around the parts of the shell that required hardness and strength. In the pavilion structure produced in 2021 with the aim of adaptability and use in interaction with the existing building stock, a floor area of 62.5 m^2 is formed by the fibers wrapped in 2.5m x 2.5m elements. Compared to the reinforced concrete slab structure of the same thickness and area (Figure 6), the unit weight is only 23.7kg/m^2 when the wooden plate to be placed on it is added compared to the 500 kg/m^2 weight (Menges & Dambrosio, 2021). It is 18 times lighter than reinforced concrete flooring.

3.4. Lightweight Structures with Elements Made of Folio material (ETFE, PTFE, PET)

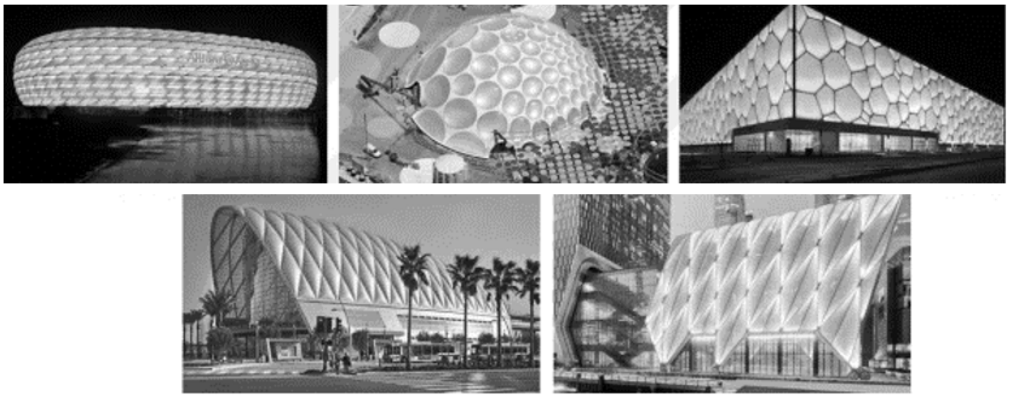


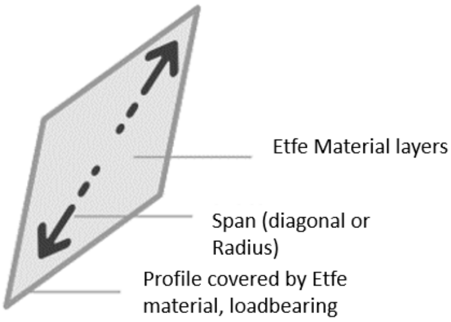
Figure 7. Visuals of the buildings produced with foil material within the scope of the study, 1-Allianz Arena (AGC Chemicals. (n.d.). ETFE film: Allianz Arena. Stylepark.), 2-Thirst Pavilion (Lastra y Zorrilla. (n.d.). Multiple layer covers and facades.), 3-Watercube National Swimming Center (Vector Foiltec. (n.d.). National Aquatics Center), 4-Anaheim Regional Transportation Center (Linden, C. J. ARTICs ETFE pillow assembly), 5-The SHED (World-Architects. (2021). A movable enclosure of air and plastic.)

When the examples in which foil systems are used are examined (Figure 7), it is seen that the general purposes are to provide a closed surface to pass a wide opening, to facilitate the movement mechanism of a large moving area, to give the space a feeling of open space.The material, light in nature, is stretched into a frame. This material, which is chosen to be light when passing wide openings in the construction of the building, comes together by forming unit elements and creates a cover.

These unit elements contain frames.In this study, which is examined for the purpose of lightness, it is seen that the number of layers of the foil material used is increased in order to reduce the number of profiles and thus the load, to increase the opening through which the unit element passes, and to keep the strength of the unit element at the same time. This relationship can be followed in Table 6.

Rather than increasing the profile thickness or number, increasing the number of layers also reduces the transmitted loads of the structure.This affects the associated detail and profile dimensions and the chosen foundation dimensions. The structures examined in the study and the unit element spacing passed depending on the number of layers used are shown in the Table 6.

Table 6. Unit element span chart of structures made of ETFE material (Boylu, 2022)



Year	Building name	ETFE için mesafe (min-max)	Layer number
2005	Allianz Arena	7.3m-17m(diyagonal)	2 layers
2008	Thirst Pavillion	2.8m-9.8m (radius)	2 layers
2008	Beijing National Aquatics Center	0-9m (radius)	3 layers
2014	Anaheim Regional Transportation Center	5m-27m (diyagonal)	3 layers
2019	The Shed	0-21m (diyagonal)	3-4 layers

3.5. Lightweight Structures with Elements Made of FRP Material

Fiber-reinforced material, which is formed by strengthening with various fibers such as glass fiber, carbon fiber and aramid fiber, is preferred in terms of use with its high strength and low weight. It was observed that the facade material and the shell were used as the main material in the structures examined (Figure 8).

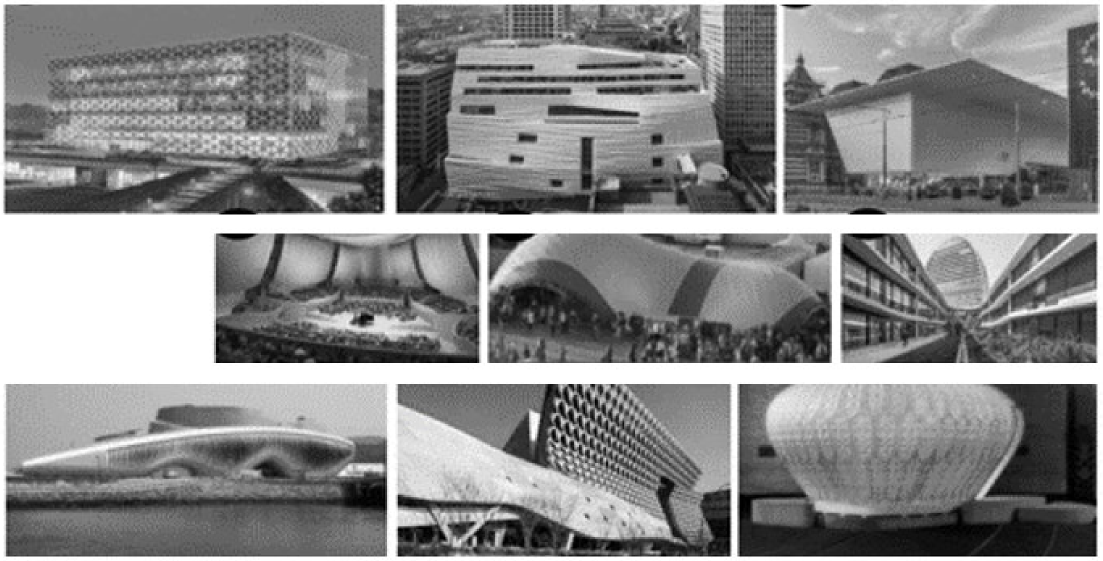


Figure 8. Visuals of the buildings produced with FRP material within the scope of the study, building names given in order on Table 7.By an order 1-Gebouw (Holland Composites., n.d.). Composite façade Windesheim Building X. Holland Composites.), 2-SFMOMA (San Francisco Museum of Modern Art., n.d.). Made in the Bay Area), 3-Stedejik Museum (e-architect., n.d.). Stedelijk Museum Amsterdam.), 4-BING Concert Hall (Bourne, 2023). Concert hall composites), 5-GFRP Gridshell (Linden, 2015), 6-BBVA HQ (Miller, 2013). Update: SFMOMA expansion by Snøhetta. ArchDaily.), 7-Yesou Expo Center(Soma Architecture., n.d.). Thematic Pavilion), 8-Kolon One&Only Center (Sweeney, 2019). Kolon One & Only Tower. Architect Magazine.), 9-Cacoon FS Pavillion (Architizer. (n.d.). Cacoon FS. Architizer.)

It can be molded, shaped by scraping with a robotic arm, and it can be applied by spraying and applying. When the examples are examined, the reasons for using these materials in buildings are shown in Table 7. In the samples examined, GFRP-CFRP and AFRP materials were mostly used as facade materials.

Table 7. Structures examined and the advantage of the material used (Boylu, 2022)

Building name	G/A/CFRP Using Advantage
01-Gebouw Prefabricated Facade	Lightweight facade
02-SFMOMA	Lightweight facade
03-Stedejik Museum	Lightweight facade
04-BING concert hall, acoustic panels	Lightweight panel
05- GFRP Gridshell	Lightweight shell
06-BBVA HQ	Lightweight facade
07-Yeseo Expo Center	Lightweight facade / lower weight through facade mechanism
08-Kolon One & Only Tower	Lightweight facade
09-Cacoon FS Pavillion	Lightweight shell

The lightening of the facade means that less load is placed on the elements carrying the facade and therefore, less material with thinner sections is used. Accordingly, the decrease in the loads transferred to the foundation means that the material required for the foundation automatically decreases.

Among the structures whose unit weights have been reached, the unit weight in the Cocoon FS Pavilion structure is 7.5kg/m^2 (Kromoser, Preinstorfer & Kollegger, 2017). Manufacturers are able to fix the structure to the ground to be able to withstand wind, etc. It is positioned on a concrete platform to protect it from external influences.

It can be said that the lightness in the building affects the other elements and element dimensions with which the lightweight construction material and the lightweight construction element interact.

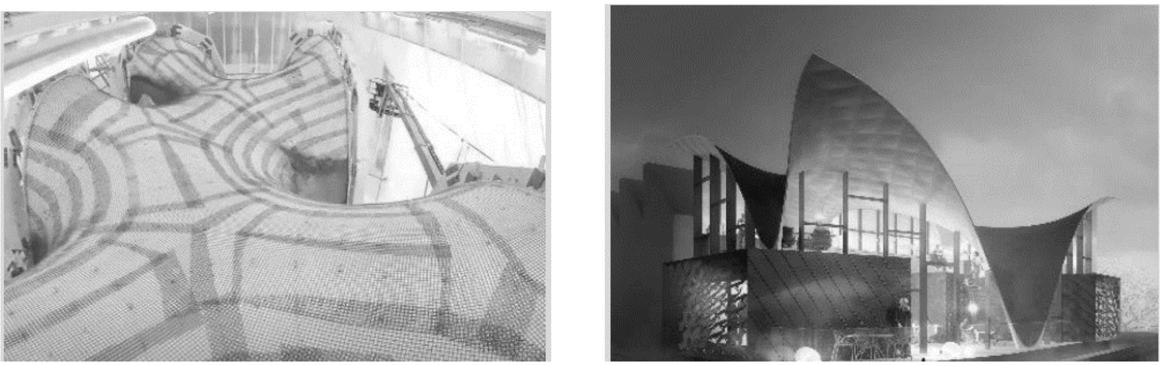


Figure 9. Images of Hilo Shell structure (ETH Zurich., n.d.). Full-scale construction prototype: NEST HiLo shell roof) (Mele et al., 2017).

The building shell system benefits from the knowledge and experience gained in the historical context by supporting it with the mesh elements and fabric used during construction (Figure 9). The shell structure is 4 cm thick and covers an area of 200 m^2 (Mele et al., 2017).

The unit weight of the building, which has a total weight of 800 kg, is only 4 kg/m^2. The benefit of thinning the cross-section provides the advantage of reducing the material used in the final product and covering a similar area with less material.

At this point, the concept of topology optimization becomes crucial in many such structures. In this example Nest Hilo, a common material like concrete has been applied using additive design methods to maximize the effect of topology optimization and achieve complex geometries.

This approach meets four key criteria: complex geometry, three-dimensional concrete printing, robotic fabrication, and material efficiency. As a result, the structure gains lightness, durability, cost and time efficiency, and sustainability. In additive manufacturing technologies, rather than designs lightened by topology optimization, it is predicted that organic forms developed to suit production parameters will shape future design trends (Çalışkan & Arpacioğlu, 2020).

4. Conclusion and Suggestions

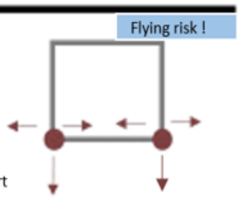
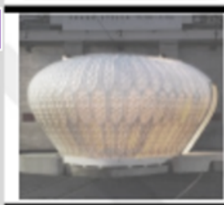
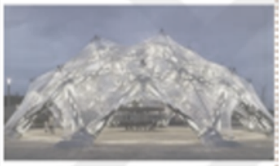
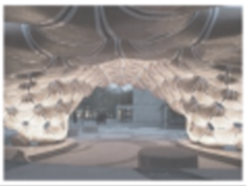
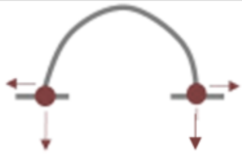
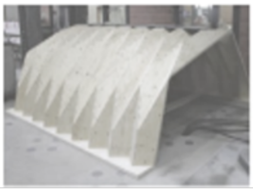
In this study, building samples made of paper, fiber reinforced plastic (CFRP-GFRP-AFRP), carbon and glass fiber, light wood, foil material (ETFE-PTFE) and ultra high performance concrete materials were examined in terms of lightness.

Lightness is divided into two as light portability and light transportability in study. For a structure to be lightly portable, it must be light enough for 2 people to carry, and this must be less than about 50 kg.

Different strategies have been tried with different materials for lightness. The inferences made when looking at the structures with the lightest unit weights are as follows:

- Different lightweight materials have different resistance to atmospheric conditions, water and humidity.
- Although it provides lightness (e.g., pop-up dome), some structures could not provide long-term life conditions. On the other hand, in structures with a durable material nature (Prayor Shelter), both lightness and durability are met. The lightness of the structure requires a connection to the ground in order to withstand impacts such as flying. Making a heavy foundation does not provide the purpose as it will make the whole system heavier. In this regard, Cocoon FS structure can be given as an example with its weighting on the system.
- Although the Apeldoorn structure, which is completely made of paper, shows that the joints can also be produced from paper, only 1 week was given to the structure, whose joints weakened due to the soft nature of the paper. In a different approach, the Cocoon FS structure is made of fiber-reinforced plastic, but incorporates steel elements so that its joints are durable. It is thought that while making the structure durable, it makes it heavier, as it is at the base of this approach.
- As with the UHPC material, although the nature of the material is heavy, its unit weight is reduced to 4kg/ $m^2$with thin sections and advanced structure technology.
- Dismantling and re-installing in structures produced with light materials is an advantage both for transportation and re-deployment, and for sustainability.
- It is deduced that the use of light material thins the profile sections used in parts where strength is important together with atmospheric conditions in the material selection (for example, on facades): therefore, reducing the amount of material used.
- Increasing the number of layers in the structures produced with foil material has ensured the passing of the span and reducion in the number of carrier profiles used.
- Studies have been carried out to increase the structural possibilities of a light material such as paper. The moisture resistance of the material has been improved over time by cutting off its contact with water, which does not aggravate the structure, such as an additional outer layer and isolation from the ground.

Table 8. Compilation and comparison of the lightest structures with data obtained as a result of the study (Boylu, 2022)

cardboard	POP UP DOME		3.125 kg/m2	15m²	<50kg	Folded- dome	+ Able to carry by 2 people ⊘ Water resistance ⊘ Long lifetime + Lightweight foundation-support	
cardboard	2-APELDOORN THEATRE		6.25 kg/m2	240m²	1500kg	shell	⊘ Able to carry by 2 people ⊘ Water resistance ⊘ Long lifetime + Lightweight foundation-support	
polipropilen	3-PRYOR SHELTER		3.97 kg/m2	4m²	15.88kg	Folded	+ Able to carry by 2 people + Water resistance + Long lifetime + Lightweight foundation-support	
FRP	4-COCOON PAVILION		75 kg/m2	10m²	750kg	Shell-segmented	⊘ Able to carry by 2 people + Water resistance + Long lifetime ⊘ Lightweight foundation-support	
Carbonfiber	5-ICD/ITKE 2018-19 PAVILION		7.6 kg/m2	400m²	3040kg	Segmented / geodesic dome	⊘ Able to carry by 2 people + Water resistance + Long lifetime ⊘ Lightweight foundation-support	
Carbonfiber	6-ICD/ITKE 2014-15 PAVILION		6.5 kg/m2	40m²	260kg	shell	⊘ Able to carry by 2 people + Water resistance + Long lifetime ⊘ Lightweight foundation-support	
Wood	7-ICD/ITKE 2015-16 PAVILION		7.85 kg/m2	85m²	780kg	Segmented shell	⊘ Able to carry by 2 people + Water resistance + Long lifetime ⊘ Lightweight foundation-support	
Wood	8-INTERLOCKING TIMBER PLATE SHELL		7.68 kg/m2	25m²	192kg	Folded shell	⊘ Able to carry by 2 people + Water resistance + Long lifetime + Lightweight foundation-support	

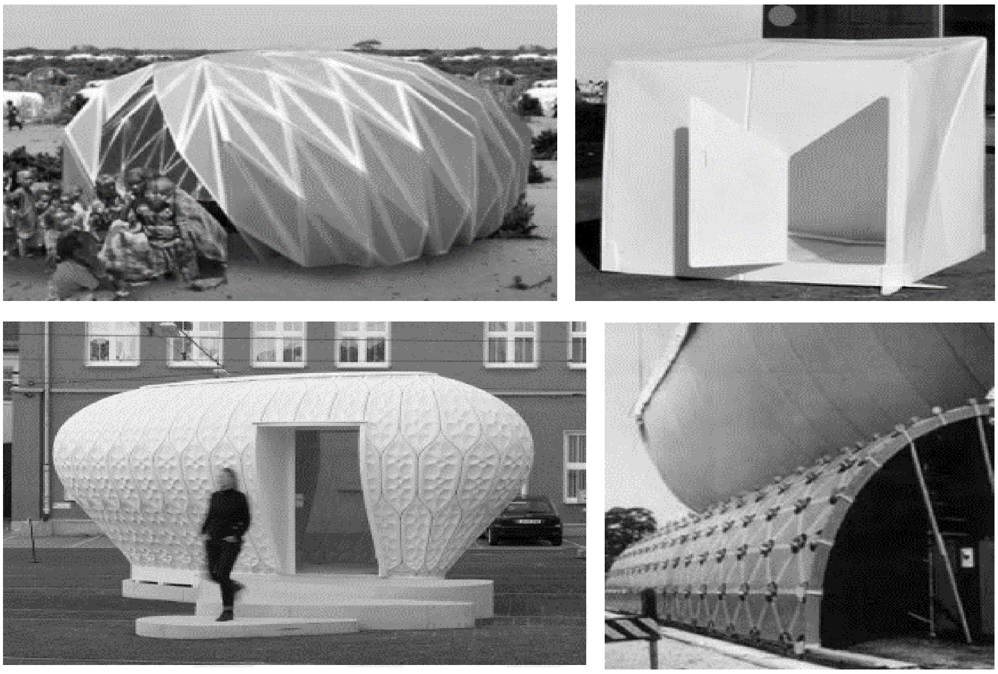


Figure 10 By an order, 1-Pop Up Dome(AIA Chicago., 2018), 2-Prayor Shelter (Pryor, 2018), 3-Cocoon FS Pavilion (Architizer., n.d.), 4-Apeldoorn Theater (Latka, 2017)

It is inferred from this study that the choice of lightweight material in the building directly affects the dimensions of the other building elements with which it interacts. This brings economy to the structure. Due to the lightness (f=m.a) formula, it is a factor that ensures building safety for earthquakes. However, the decrease in mass creates a negative effect due to the danger of flying against factors such as wind (Figure 10). It requires ground fixing. The lightness of the unit element of the system provides lightness in the structure, but for the structure to be light as a whole, the foundation and its joints must also be light.

As a result, in this article the lightest structures of each material were compared, and it was concluded that lightness affects structural configuration, structural connections, and structural subsystems. The direct impact of lightweight materials on structural subsystems provides benefits such as construction economy and ease of assembly throughout the structure. Additionally, instead of evaluating the results solely in terms of lightness, this study developed an approach to examine structural requirements and reconsidered situations where lightness could cause certain disadvantages. As a result of this evaluation, considering the four basic criteria (portability by two people, wind resistance, water resistance, and the ability to be established with a lightweight foundation system), it was found that both the lightness and the nature of the material are important criteria for the reuse or long-term durability of the structure. This study aims to contribute to the literature by covering a broad range, from the use of simple, economical materials like cardboard to complex, advanced materials such as carbon fiber and robotic fabrication processes, while examining applied structures through the lens of lightness. These results suggest that in today's world, where resource management has become increasingly important, lightness will be a fundamental element in creating more sustainable, faster, and more economical buildings.

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The article complies with national and international research and publication ethics.Ethics Committee approval was not required for the study.

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