

## ENHANCEMENT OF CONCRETE ELEMENTS AND ITS EFFECT ON NATURAL LIGHTING

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### ABSTRACT:

this paper proposes to study the role of structural elements in buildings for functional, aesthetic aspects and lighting and Interest in the optimization of the structural system for load-bearing walls of concrete to increase the external lighting openings and reduce the cost while enhancing the strength of concrete as well as reducing its density. The problem lies in the fact that the bearing walls of the walls have less use of lighting openings in addition to the high cost due to the use of the traditional process of design without use optimization processes of design as they have a major role in reducing the cost while maintaining the aesthetic required. During this study, this accomplished through analyzing the case studies of the broad museum building and the Victoria Gate where different types of concrete used. SolidThinking Inspire used to create the study model using the morphology tool. The design of the model depends on the algorithm for optimization of the topology, and the optimization models compared with the case studies selected before the improvement process in terms of shape, increase in stiffness, the difference in density, and area of the lighting openings. The optimization results found to be effective and designed with the highest strength to prevent deformation that reflected in the increase in lighting openings and reduce cost.

**KEYWORDS:** Optimization, 3D Printing, Concrete, Cost, Lighting Openings.

### تحسين العناصر الخرسانية وتأثيرها على الإضاءة الطبيعية

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### الملخص:

تهدف هذه الدراسة إلى دراسة دور العناصر الإنشائية في المباني من الناحية الوظيفية والجمالية والإضاءة والاهتمام بتحسين النظام الإنشائي لواجهات الحوائط الحاملة من الخرسانة وذلك لزيادة فتحات الإضاءة الخارجية والتقليل من التكلفة بجانب تعزيز متانة الخرسانة وتقليل كثافتها. تكمن المشكلة في أن واجهات الحوائط الحاملة تقل فيها استخدام فتحات الإضاءة نظراً لأن هذا النظام الإنشائي لا يسمح فيه باستخدام فتحات إضاءة بمساحات كبيرة في الحائط الخارجى بالإضافة إلى أنها تحتاج إلى تكلفة عالية ويرجع ذلك إلى استخدام الطرق التقليدية في التصميم دون الإستعانة بعمليات تحسين التصميم حيث يكون لها دور كبير في تقليل التكلفة مع الحفاظ على الشكل الجمالي المطلوب. خلال هذه الدراسة يتم تنفيذ

ذلك من خلال تحليل دراسات الحالة لمبنى المتحف الواسع وبوابة فيكتوريا حيث استخدمت انواع مختلفة من الخرسانة. تم استخدام برنامج SolidThinking Inspire لإنشاء نموذج الدراسة باستخدام أداة التشكل. يعتمد تصميم النموذج على خوارزمية تحسين الطوبولوجيا وسيتم مقارنة النماذج بعد عملية التحسين مع دراسات الحالة المختارة قبل عملية التحسين من حيث الشكل وزيادة الصلابة واختلاف الكثافة ومساحة فتحات الاضاءة بالمبنى وكيف يؤثر ذلك التحسين على تقليل التكلفة لكل نموذج. تم العثور على نتائج التحسين لتكون فعالة ومصممة بأقصى صلابة من أجل منع التشوه الذي ينعكس بوضوح في زيادة فتحات الاضاءة وتقليل التكلفة خلال مراحل التصميم الأولية.

**الكلمات المفتاحية :** تحسين ، الطباعة ثلاثية الأبعاد، الخرسانة، التكلفة، فتحات الإضاءة.

## 1. INTRODUCTION

The structural form directly affects the areas of the lighting openings in the building facades. Thus, the process of enhancing the shape and characteristics of the load-bearing wall of hardness and low weight helps directly in increasing the natural lighting openings of the building. In the past decade, the use of structural optimization has increased rapidly. The upstream phases of the design process account for 5 percent of the time spent on product development but represent 75 percent of the global development costs (Sharpe JEE, 1995).

This is critical when bringing optimization into a project's early stages. It has become important to use Algorithms to refine the goods to check that materials and shapes. Through developments in computer science and technology, structural engineering modeling has become one of the most critical means of achieving lightweight, high-performance structures. Structural optimization usually divided into optimization of scale, form, and topology, based on the various architecture variables. Topology optimization was deemed the most common of these three optimization approaches as it can provide engineering designers with fresh and often even unexpected concepts without needing a pre-established plan. Optimization of topology, in general, uses optimization methods to seek to figure out where to put the material in the architecture environment (Bendsøe, Sigmund, 1999). Topology optimization has experienced rapid growth over the past four decades and has been extended effectively to structural architecture in many manufacturing fields, including the automobile, aerospace, and biomedical industries (Zhu, Zhang, Beckers, 2009).

Many different approaches are suggested for optimization of topology, including the density system (Liu, Hu, Li, Zhou, Dong, 2014), it is among these approaches the evolutionary approaches Bi-directional Evolutionary Structural Optimization (BESO) and Evolutionary Structural Optimization (ESO), and Bi-directional evolutionary Structural Optimization (BESO) (Xie, Steven, 1993). Among such methods, the density approach used to define the structural topology by using element-constant density is the most advanced methodology owing to its computational stability and efficiency.

## 2. FORMULATION OF PROBLEM

Optimization of shape, function, and substance in architectural models as distinct areas has culminated in the wasteful usage of structural materials in architectural designs (Oxman, 2010). Enhanced design and structural efficiency is necessary to integrate framework, design, and shape into a single feature load-bearing wall-and to overcome the issue of facade positioning and to avoid the use of substructures and structural barriers inside facades In addition to improved natural lighting.

The application used aims to add the mechanical properties and behavior of load-bearing walls in the early stages of design by developing their functional and structural performance, and their direct impact on the lowering expenses, and increasing lighting openings that contribute to increasing the proportion of natural lighting. The technology used in the optimization process is a set of metrics defined within the application (shape support cases - loads - openings size).

## 3. ROLE OF STRUCTURE IN INCREASING NATURAL LIGHTING

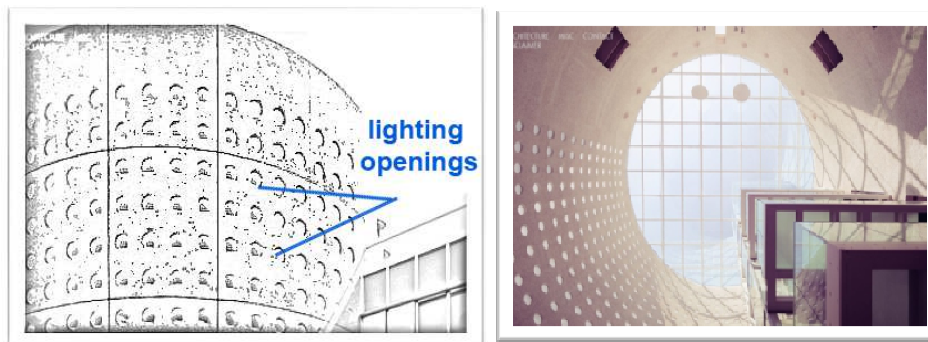
To increase daylight levels and to increase transparency through the building's envelope, the architects make some modifications to the structural details. The lighting can be an increase in

interior space and using natural lighting by reducing the size of the structural elements and creating openings in them that allow the passage of natural light within the internal space of the building.

### 3.1. Breakthroughs in Structural Elements

Breakthroughs in structural elements are one aspect of structural detail. Sometimes the details require a greater amount of natural lighting. Breakthroughs in structural elements give it lightness and increase the amount of natural light. It is an increasingly popular technology that it gives for the lightness more than a source of natural light. In general, windows and openings breakthroughs the concrete walls, but when lighting is more important than visibility, making smaller, more numerous breakthroughs is more appropriate (Michael & Ashby, 1999).

At the Mexican Embassy in Berlin, the main cylindrical lobby is behind the embassy facade, where the outer wall forms a part of the concrete cylinder surrounded by daylight, carved with circular holes that give the concrete wall a lightweight feel and increasing of the natural light shown in **Fig. 1**.



**Fig. 1: The Mexican Embassy in Berlin** (Jan Rottler, 2019)

### 3.2. Modify For Lighting

The structure is not only a source of light but sometimes is designed to increase the amount of light inside the building or to adjust the intensity and quantity of light. The structure can also obscure the light with its opacity, or the structure can be used to light or reverse the light.

#### 3.2.1. Filter of Light

The many structural elements located in layers and close spaces have the property of filtering the light inside the place.

For example, the internal structure of the ceiling of the listening hall at the Wolan High School Auditorium see **Fig. 2** The roof plays a strong role in filtering light through the upper glass between structural elements, where the functional role of the main arches is a filter for light, giving the reflection of natural and artificial light in different lighting conditions (Zajonc, 2006).



**Fig. 2: Wolan High School Auditorium** (Galinsky, 2006)

### 3.2.2. The Structural Elements Reflection of Light

The structural elements block direct sunlight, but they can also reflect and spread it into the surrounding spaces. In the Mönchengladbach Museum, the ceiling parts of the museum receive a large direct light. Because of its light color, it plays an influential role in blocking sunlight and reversing it into the spaces of the display see **Fig. 3**, (Andrew, 2005).



**Fig. 3: Ceiling of Mönchengladbach Museum by Architect Hans Hollein** (Rykwert, 2014)

In the expansion of the Denver Museum of Art by architect Daniel Lipskind, and it's an exhibition of contemporary art collections, architectural collections, and spatial art. It is a building of reinforced concrete and clad with titanium, the structural elements on the ceiling receive direct sunlight and spread it inside the space to reflect it artistically, so the light becomes part of the show inside the museum. In **Fig. 4**, illustrates the optical experiments provided by structural elements in the reflection of natural light. "One of the challenges at the Denver Museum is responding to the changes in the wide range of lighting, color, surrounding influences and the distinctive climate in this city, and I emphasize the integration of these elements not only functional and physical but also cultural and add fun experiences to benefit a museum visitors," says Lipskind. The architect used the structural elements of the ceiling and walls to modify the natural light that penetrates the interior spaces through the specific glass surface, intertwined with the solid structural elements (Elizabeth, 2009).



**Fig. 4: The Denver Museum of Art** (ArchDaily, 2020)

The textile properties have the characteristic of reversing and diffusing light. Their glossy and white surfaces, except for the sun-warmed dark tissues, ensure a high degree of reflection. The fabric's ability to diffuse and diffuse light tested on a sunny day. The transparency varies according to its thickness and quality, Low, and stable comfort.

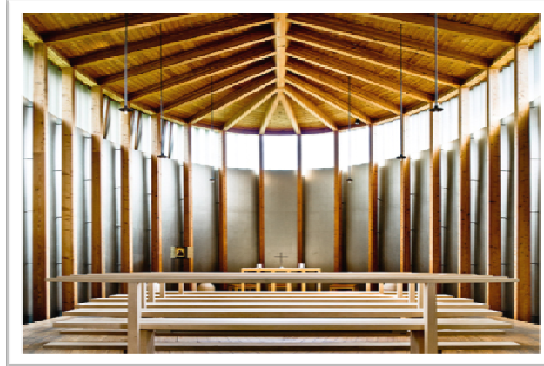
### 3.3. Light Modifies the Visual Size of the Structural Elements

Often the structural elements control the quality and quantity of lighting inside the building, but the light relation is not entirely influenced by structural elements, as the light reveals the details of the structural elements as it modifies the human perception of its size. The phenomenon of non-enactment occurs when areas of the structure exposed to higher degrees of illumination than ambient light, to the extent that they lose their shape in the blurry brightness. The columns that continue through the windows represent this situation in the wooden Showroom Hergatz where the wooden columns passing through the windows are lighting when the sun is bright so that they merge with the total brightness in the background and the columns look as if they are not attached to the ground and stand at the top of the window line. But this visual effect becomes unnoticeable on a hazy day see **Fig. 5**, (Charleson, 2015).



**Fig. 5: Showroom Hergatz** (Baumschlager architekten, 2019)

In the internal structure of the Church of Benedict, we find a similar effect to the exegesis in the previous example using lighting as the columns pass in front of the upper windows of the church and the brightness of the surfaces and glow, which reduces the clarity and intensity of shades, Reinforcing the belief that the roof is floating see **Fig. 6**.



**Fig. 6: Benedict Chapel Saint** (Peter Zumthor, 2020)

## 4. OPTIMIZATION PROCESS OF STRUCTURE

From the above, we note that the external structure in the buildings has a great role in determining the features of the building and its shape, as well as determining the amount of natural light and how to direct it inside the building through the size of lighting openings, especially in the load-bearing walls. So it was necessary to make an optimization for this type of buildings in order to reach the best form of the structural elements at the lowest cost, in addition to optimizing the lighting openings and providing maximum natural lighting for the building.

### 4.1. Software and Material Selection

Technological advances in parametric modeling make it possible to influence the large-scale processing of complex forms. Using a generative series and the interaction between geometric artifacts, the parametric architecture method introduces meaning to a geometric paradigm. Reinforced concrete provides tensile strength, such as steel plates, and is immune to physical impacts (Wilfredo Méndez, 2019), Where all substrates are composite and isotropic,

SolidThinking Inspire 2019 load-bearing wall modeling software is the preferred program. The use of a morphology instrument focused on the design of topology and parametrics, which are often complex forms and difficult to design. Shape Optimization creates efficient structures of lightweight that meet the demands of weight, strong performance.

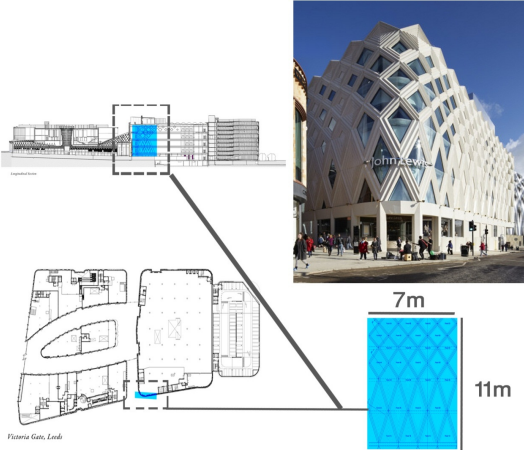
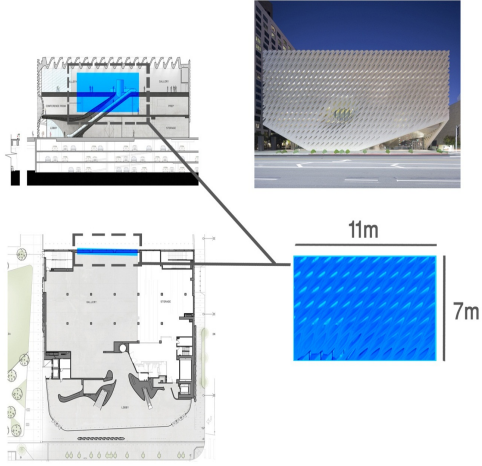
**4.2. Portion Weight Calculations**

This optimization focuses on the structure dimensions 11m × 7m for the case studies where the 3D printing machine model size is 22cm x 14cm (All3DP team, 2020), a scale used in the optimization process is 1:50. The weight and resistance of the structures compared to the selected case studies.

**4.3. Case Studies Selection**

The chosen Case studies of structures are (Victoria Gate, And the Broad Museum). **Table 1**, shows the section of study form that will be optimization is 7m x 11m, in (Victoria Gate) the density white concrete 3150 kg / m<sup>3</sup>, whereas in (Broad Museum) the density concrete 1800 kg / m<sup>3</sup>, it is used for panels made from fiberglass-reinforced concrete martial (Shakor, Pimplikar, 2011).

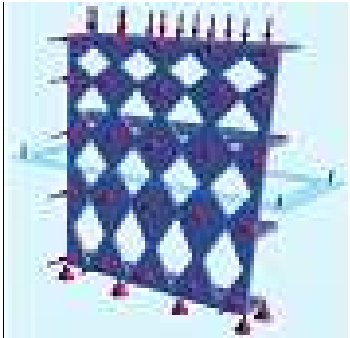
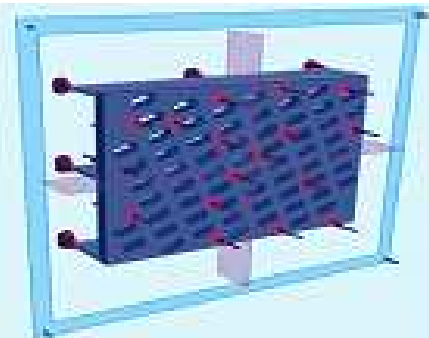

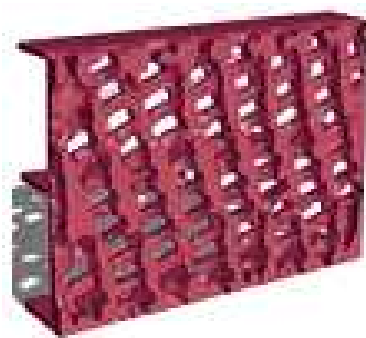
**Table 1: Calculations of Victoria Gate Building and the Broad Museum Building**

	VICTORIA GATE IN LEEDS CITY CENTRE		THE BROAD MUSEUM IN LOS ANGELES	
SECTION OF THE STUDY				
CALCULATIONS	Openings percentage	34% of the façade	3 X 6 m panel weighs	6.8 ton
	Wall thickness	0.4m		
	Total Concrete Area	7 X 11 = 77 m <sup>2</sup>	panel Area	3X 6 = 18 m <sup>2</sup>
	Total Openings Area	26.18 m <sup>2</sup>		
	Gross Concrete Mass	Density X Volume = 3150 X (7 X 11 X 0.4) = 97020 kg	Total Concrete Area	7 X 11 = 77 m <sup>2</sup>
	Gross Openings Mass	Density X Volume = 3150 X (26.18 X 0.4) = 34986 kg	number of panels	77/ 18 = 4.2 panel
	The total mass of concrete	97020 – 34986 = 62034 kg = 62 ton	The total mass of concrete	4.2 X 6.8 = 28.56 ton

**4. 4. Solidthinking Inspire Outputting Model**

The following **Table 2**, summarizes the comparative results of the material optimization and structural quality contrast factors between the models produced by solidthinking inspire software and the case study design of the buildings and produce models of 3D printed with a lower density ratio for the materials used and how the optimization affected the form of the wall by increasing the lighting openings area. after the optimization process, the biggest decrease was in the first case, white concrete material, and then comes the second case which used Fiberglass Reinforced Concrete material, which indicates that the use of improvement differs from one substance to another, Where optimization occurs at the maximum degree for untreated conventional materials, which results in a decrease in density and therefore a reduction in cost.

**Table 2: Comparison of Material, Structural Efficiency, and 3D Printed models before and after optimization For Case studies**

	Victoria Gate	The Broad Museum
Material	White Concrete Panels (Density = 3150 kg/m <sup>3</sup> )	Precast Fiberglass Reinforced Concrete Panels (Density = 1800 kg/m <sup>3</sup> )
Model to optimize		
Weight of (11m X 4m) Exterior Load-Bearing wall section before optimization	62 ton	28.56 ton
Weight of (11m X 4m) Exterior Load-Bearing wall section after optimization	53.514 ton calculation by solidThinking Inspire	25.01 ton calculation by solidThinking Inspire
Model of 3D Printed		

### 5. RESULTS AND DISCUSSION

Through the analytical study of the previous examples, see Fig. 7, which explains the role of structure and lighting:

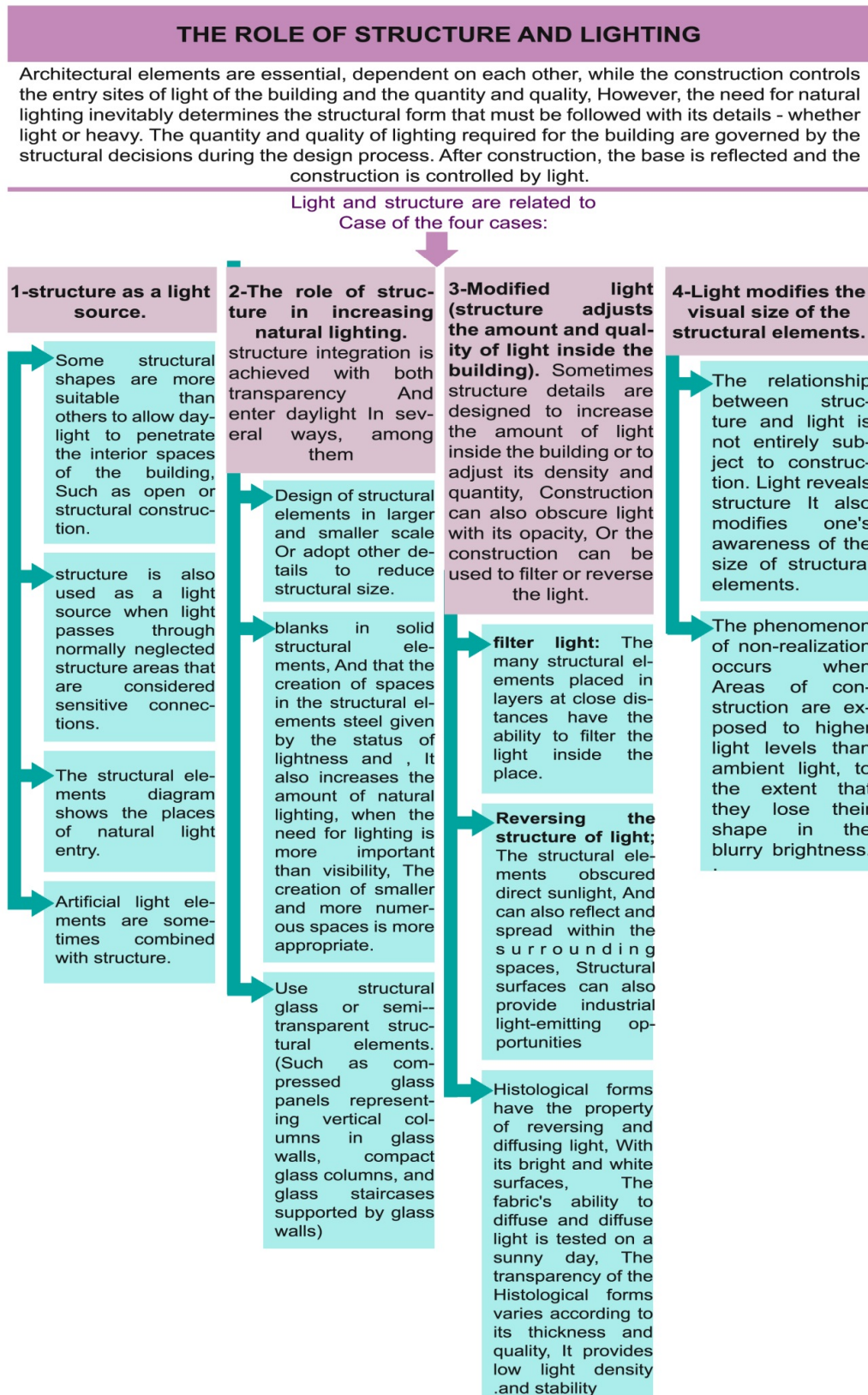


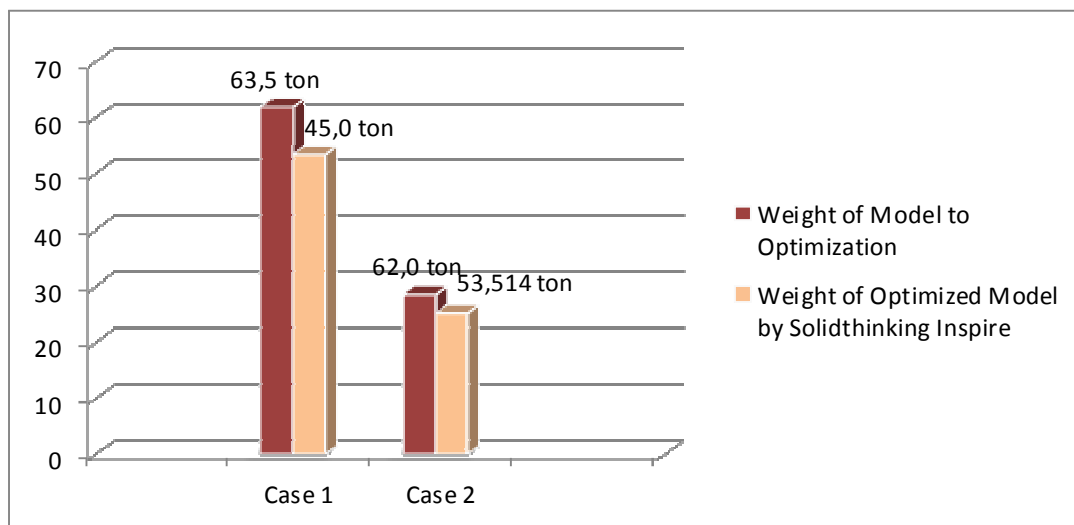
Fig.7: The Role of Structure and Lighting.



The goal of the improvement was to optimize hardness to achieve the lowest density of the material and thus the lowest cost while maintaining the shape and preventing deformation besides having more space for the lighting openings. The structural wall optimization offers mechanical properties where a structure weights 13% less than equivalent cases before optimization. You will find the increase in the percentage of lighting openings, the lower the percentage weight of the materials used, where in the first case, the rate decreased by 13.7% from 62 tons to 53.514 tons, in the second case it decreased by 12.4% from 28.56 tons to 25.01 tons. Lighting openings percentage of total mass before and after optimization in the first case from 34% to 47.7% and in the second case from 30% to 42.4% as shown in **Table 3** and **Fig. 8**.

**Table 3: Percentage of Materials used for Maximum Strength, Less Weight and more Lighting Openings**

Projects Martial	Weight rate before Process Optimization	Weight rate after Process Optimization	Percentage of reduce material weight	Lighting openings percentage of total mass before Optimization	Lighting openings percentage of total mass after Optimization
Victoria Gate White Concrete Panels	62 ton	53.514 ton	13.7%	34%	47.7%
The Broad Museum Fiberglass Reinforced Concrete Panels	28.56 ton	25.01 ton	12.4%	30%	42.4%



**Fig. 8: Reduce Weight of Load-Bearing Wall after Process Optimization.**

**6. SUMMARY AND CONCLUSIONS**

- The relationship between structure and lighting is not entirely subject to the structure. The light reveals the structure as it modifies realize of the structural size elements clearly, so if studying natural lighting professionally, it reduces the severity of the structural elements.
- Non-embodiment phenomenon occurs when areas of the structure exposed to greater degrees from lighting to the point that they lose their specific form in fog brightness.
- The use of the software makes it possible to develop a wide range of structural solutions and their performance for the natural lighting function of the building.
- Use of mechanically engineered actions on the load-bearing wall in the early stages of architectural design to create its content and structural efficiency; The approach used to

address the problem is to combine increasing of the established parameters such as load instances, supports, the volume of construction and materials:

- 1) Scale dimension for the Maximum 3D printing system is 14 x 22 cm, maintain a scale of 1:50; a 7 x 11 m section of the structural skin was analyzed during the experimental test.
- 2) The structural wall surface is modeled and developed with software (solidthinking inspire) using a topology optimization algorithm.
- 3) The optimization of mechanical properties on the structure wall surface gives a structure, which is 13 % less in weight and more in lighting openings than the comparable cases.
- 4) The usage of content enhancement algorithm systems has a direct connection between shape and functionality. As for the improvement of white concrete, it resulted in lower density, hardness, and better surface quality than fiberglass-reinforced concrete. White concrete used to build lightweight structures after improvement, which is more structurally functional.

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