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**MilitaryTechnicalCollege
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Optimization of Load-Bearing concrete Wall Using Genetic Algorithm To achieve Mechanically Integrated Behavior.

Sara N. Elkabany[1], Ahmed M. Elkordy[2], Hesham A. Sobh[3]
[1]Assistant lecturer at Architecture Department, Faculty of Engineering, Al-Azhar University, Cairo, Egypt.
[2] Professor & Head of Architecture Department, Faculty of Engineering, Al-Azhar University, Cairo, Egypt.
[3] Professor of Architecture & Vice Dean of Faculty of Engineering, Al-Azhar University, Cairo, Egypt.

Corresponding author: Sara.alkabany@azhar.edu.eg

This paper proposes mechanical and growth characteristics of nature that inspire shapes to be applied to load-bearing walls. The problem is that this type of buildings needs a high cost due to its design without using optimization processes that have a big role in reducing cost while maintaining the required aesthetic shape. In this study, this is performed by analyzing the case studies of O-14 Building, Victoria Gate and The Broad Museum where the building materials used differ from case to case. A model was created through the SolidThinking Inspire program using the morphogenesis tool. The model design is based on the algorithm for topology optimization and will be compared in terms of structural and material performance with the selected case studies. Optimization results are found to be effective and designed with maximum stiffness in order to prevent deformation which is clearly reflected in the cost estimate in the initial design stages.

Keywords: Genetic Algorithm, Topology Optimization, Load Bearing Walls, Generative Design, 3D printing.

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1. Introduction

The use of structural optimization has rapidly increased over the last decade. The upstream phases of the design process account for 5 percent of the time involved in product development, but they represent 75 percent of the global development costs [1]. This is very important to integrate optimization into the early stages of a project. The use of genetic algorithms to optimize products has become necessary to test various materials and forms. Structural optimization design has become one of the most important ways of obtaining lightweight and high-performance structures with advances in computer science and technology. Structural optimization is generally divided into size, shape and topology optimization, depending on various design variables. Topology optimization is considered the most generic of these three methods of optimization because it can provide new and sometimes even unforeseen design ideas to engineering designers without requiring a pre-established design. Topology optimization, in general, utilizes optimization techniques to try to find out where to position content in the design realm .

Over the past four decades, topology optimization has achieved rapid development and has been successfully applied to structural design in many industrial sectors, including the automotive, aerospace and biomedical industries [2][3]. Many specific methods of topology optimization are proposed, including the density method [4][5], evolutionary approaches bi-directional evolutionary structural optimization (BESO) and Bi-directional Structural Optimization (BESO) and Structural Evolutionary Optimization (ESO) evolutions [6]. Of these methods, the density method, utilizing element-constant density to characterize the structural topology, is the most advanced technique due to its computational efficiency and stability.

2. Methodology

Model design based on the optimization algorithm for structural and physical performance, they were compared with the three case studies of the selected buildings O-14 Building, Victoria Gate and The Broad Museum, Where the results of the Optimization were found to be effective and designed with the utmost rigidity In order to prevent deformation Which resulted in reducing the cost in the initial design stages based on the characteristics of each material, which differ from one to other.

The model input parameters (design volume, materials, and loading conditions) interact as they affect each other. Integral systems are inseparable and are given a direct integration result. The aim of this study is possible to produce shapes with distributed loads directly related to the shape and materials used. The methodology followed in this work is illustrated on Fig. 1.

3. Material and Software Selection

Technological developments in parametric design make it possible to shape the large-scale production of curved forms. Through a generative sequence and relations between geometric objects, the parametric design approach presents logic into a geometric model. Applications available on the market include Grasshopper TM, Para Cloud TM, SOLIDTHIKING INSPIRETM, TOPOSTRUCTM and CATIA TM for parameter modeling tool for free-form structures.

As for the modeling instruments to implement parametric models, geometric factors need to be easily applied and easily reflected by designers throughout their modeling phase. In Table 1. the instruments were compared the tools with a variety of user comfort views. Every instrument is shown by levels in each category.

Reinforced concrete offers tensile strength such as steel plates, and is resistant to metal pressures such as concrete [7]. Where both substrates are composites and isotropically performed, the software for modeling load-bearing wall SolidThinking Inspire 2019 is the chosen software. The use of an instrument of morphology based on optimization of topology and algorithms which attempt to imitate the growth and weight of natural shapes. Morphogenesis produces effective lightweight structures that fulfill the weight, stiffness and strength efficiency requirements.

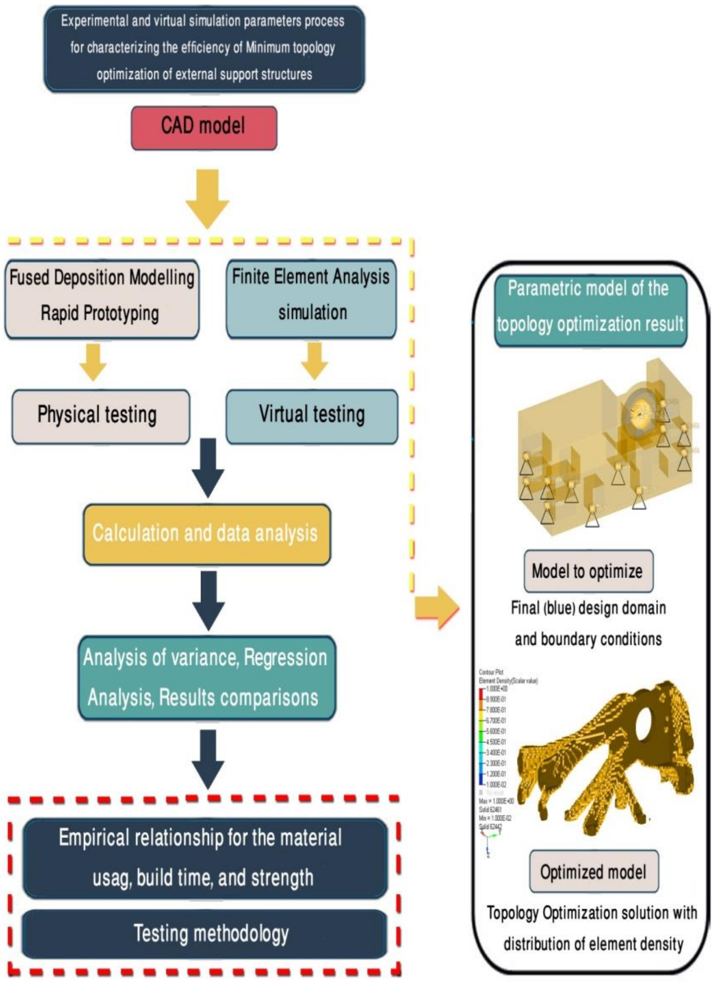


Figure 1: Load-Bearing wall Process Optimization.

Table 1. Free-Form Analysis Tools Comparison. [8]

Division	Usability	Learnability	Popularity	Compatibility	Comprehensive Evaluation
Grasshopper	medium	medium	medium	High	High
ParaCloud	medium	medium	Low	High	medium
SOLIDTHIKING INSPIRE	High	High	medium	medium	High
TOPOSTRUCT	medium	medium	medium	medium	Low
CATIA	High	medium	medium	Low	medium

4. Formulation of Problem

The optimization of form, structure and material in architectural models as distinct fields has resulted in inefficient use of structural materials in designs of architecture [9]. Improved material and structural performance is important in order to combine form, material and structure into one single feature-the load-bearing wall- and to solve the question of facade placement and stop utilizing substructures and structural obstacles within facades.
The goal of Application is applying mechanical growth and behavior in the early stages of architectural design to a bearing wall is to build its physical and structural efficiency. The strategy used to solve the problem is the chosen metrics method (known parameters problem - loads - support conditions - design size).

5. Applied Forces [10]

5.1. Loads of Gravity (Vertical Loads)

(Live Loads) are the loads that can alter in magnitude, including all products that are found in a construction during its lifetime (individuals, furnishings, safes, libraries, vehicles, machines, equipment or deposited equipment). Construction codes generally specify the magnitudes of building design live loads. Usually defined live loads for houses as evenly spread surface loads. (Dead loads) are steady magnitude loads and set locations that operate on the structure continuously. These stresses comprise the weight of the structural system itself and the rest of the structural system's materials and machinery.

5.2. Loads of Lateral (Horizontal Loads)

Lateral loads provide live loads that serve as the main component with horizontal force on the structure. A normal lateral load becomes a wind load against an exterior or storm. Most horizontal stresses differ in strength based on the place of the building, building equipment, height and structure of the building.

6. Selected Case Studies

The focus of this research is a rectangle 11 meters broad and 7 meters on the case study building's structure. A model size for the Maximum 3D printing machine is 14 x 22 cm, use a scale of (1:50). A model part of the same dimension is to be investigated from weight and resistance comparative directions compared with the following selected case studies structures:

- Victoria Gate in Leeds City Centre.
- O-14 Folded Exoskeleton in Dubai.
- The Broad Museum in Los Angeles.

7. Selected Case Studies Portion Weight Calculations

Table 2, Table 3, and Table 4. Show typical for O-14 and Urban Hive buildings, a 7 X 11 m of the external skin portion will be studied.[11] in (VICTORIA GATE) white Concrete density calculations is 3150 kg/m3, in (O-14 FOLDED) calculations Reinforced Concrete density is 2500 kg/m3, While in (Broad Museum) concrete of density 1800 kg/m3 [12] is used for the panels are made of fiberglass-reinforced concrete.

Table 2. Calculation of Victoria Gate Building in Leeds City Centre.

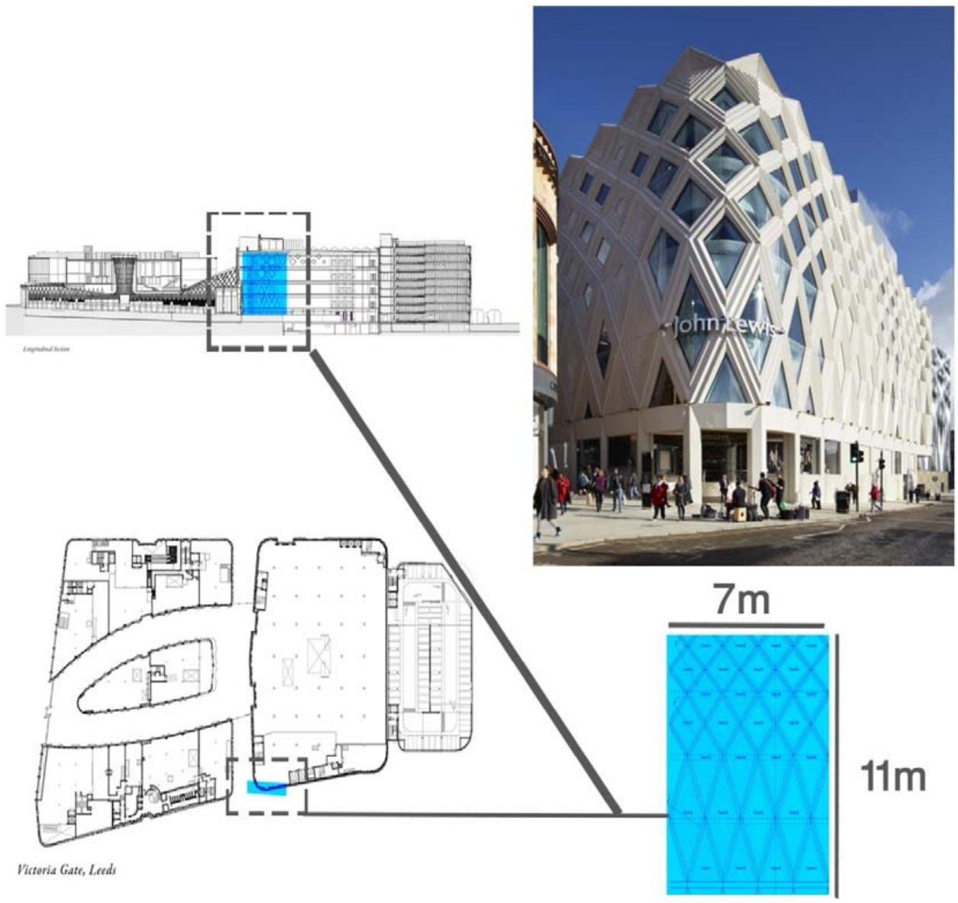
	VICTORIA GATE IN LEEDS CITY CENTRE	
SECTION OF THE STUDY		
CALCULATIONS	Openings percentage	34% of the facade
	Wall thickness	0.4m
	Total Concrete Area	7 X 11 = 77 m2
	Total Openings Area	26.18 m2
	Gross Concrete Mass	Density X Volume = 3150 X (7 X 11 X 0.4) = 97020 kg
	Gross Openings Mass	Density X Volume = 3150 X (26.18 X 0.4) = 34986 kg
	Net Concrete Mass	97020 – 34986 = 62034 kg = 62 ton

Table 3. Calculation of O-14 Folded Building in Dubai.

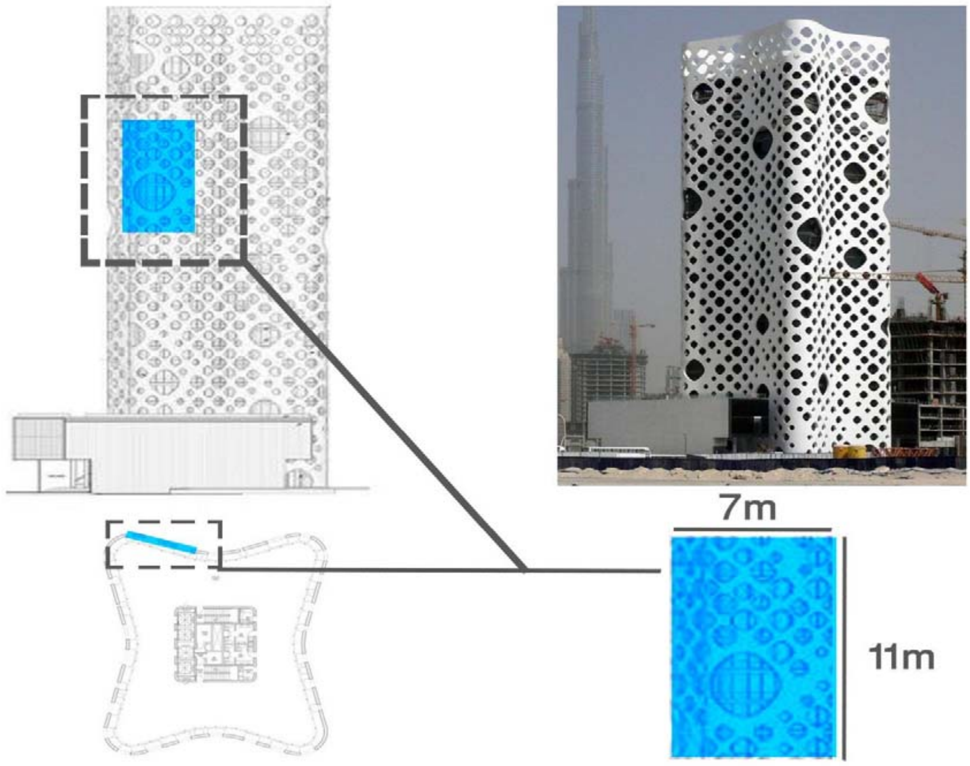
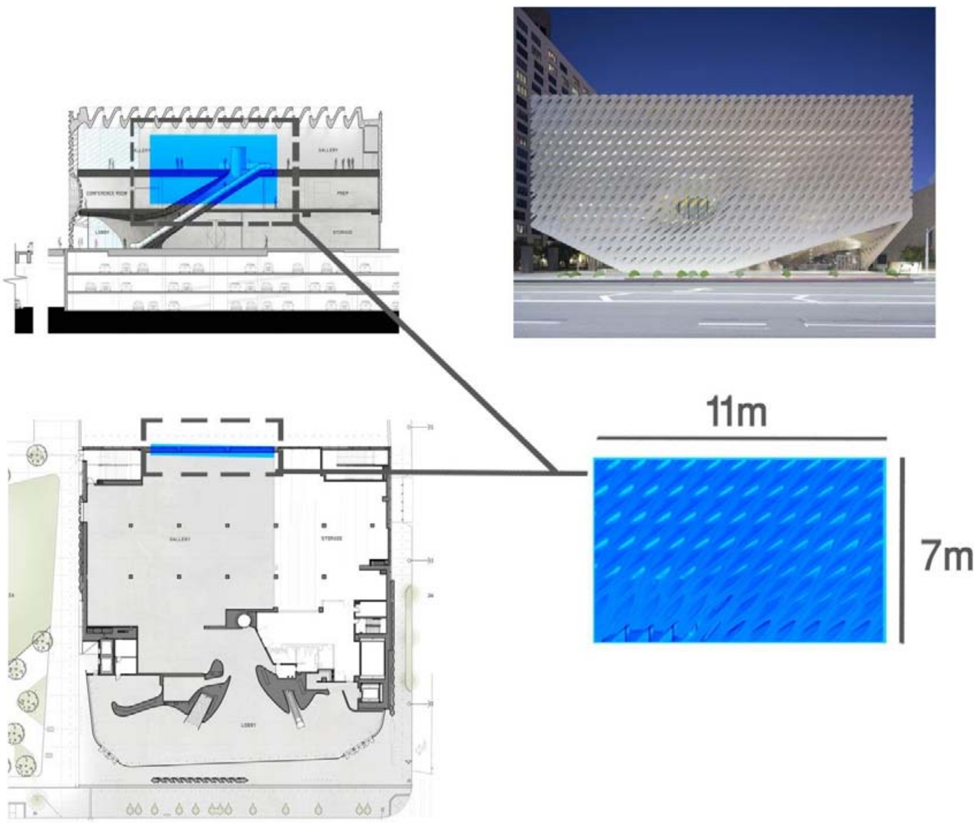
	O-14 FOLDED IN DUBAI	
SECTION OF THE STUDY		
CALCULATIONS	openings percentage	45% of the facade
	Wall thickness	0.6m
	Total Concrete Area	7 X 11 = 77 m2
	Total Openings Area	34.65 m2
	Gross Concrete Mass	Density X Volume = 2500 X (7 X 11 X 0.6) = 115500 kg
	Gross Openings Mass	Density X Volume = 2500 X (34.65 X 0.6) = 51975 kg
	Net Concrete Mass	115500 – 51975 = 63525 kg = 63.525 ton

Table 4. Calculation of the Broad Museum Building in Los Angeles.

<table>
<tr><td></td><td colspan="2">THE BROAD MUSEUM IN LOS ANGELES</td></tr>
<tr><td>SECTION OF THE STUDY</td><td colspan="2">
</td></tr>
<tr><td rowspan="5">CALCULATIONS</td><td>3 X 6 m panel weighs</td><td>6.8 ton</td></tr>
<tr><td>panel Area</td><td>3X 6 = 18 m2</td></tr>
<tr><td>Total Concrete Area</td><td>7 X 11 = 77 m2</td></tr>
<tr><td>number of panels</td><td>77/ 18 = 4.2 panel</td></tr>
<tr><td>Net Concrete Mass</td><td>4.2 X 6.8 = 28.56 ton</td></tr>
</table>

8. Process of Generating Model of Solidthinking Inspire

This program optimization is executed as indicated in Fig. 2. In order to generate an objective structure (maximum stiffness) with the following parameters:

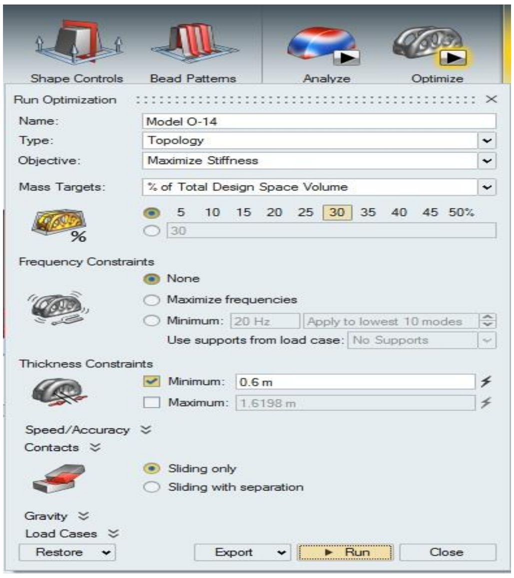


Figure 2: Program Run Optimization.

9.1. Target of Mass and Thickness Minimum

(30% of the total volume of design space) When mass objectives are used to define the amount of material to be kept, this target can either be defined as a percentage of the total design area volume or as the entire weight of the entire model. In a (Run Optimization) window, a preliminary minimum and (0.6 m) thickness may be regulated by specifying the minimum and/or maximum density.
The thickness of the design can be modified by the slider bar in the form explorer after optimization shown in Fig. 3, (Topology slider in the design space adding or extracting material from the design area in the form explorer) [13].

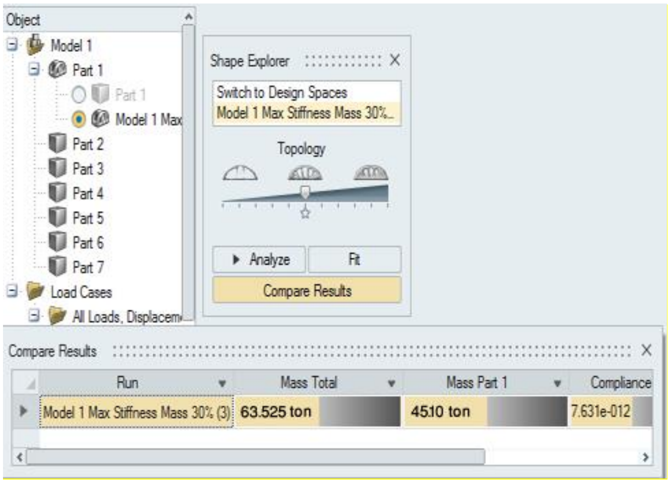


Figure 3: Shape Explorer and Compare Results.

9.2. Distribution of Forces and Supports

Structural skin forces and supports are shown in Fig. 4. Where the conditions of load are a lateral forces operating in the direction of the (+ X-axis) and the gravity loads operate in the position of the (–Y-axis). [14]

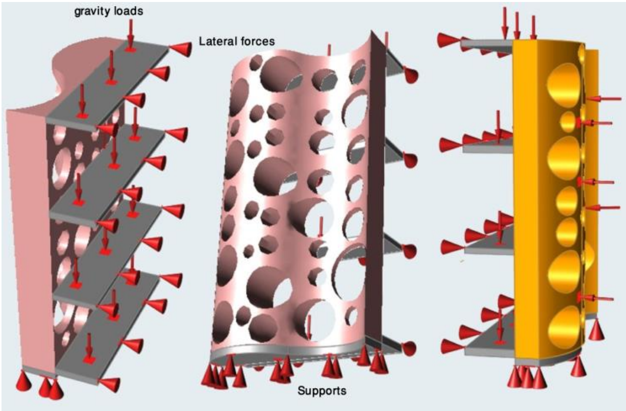
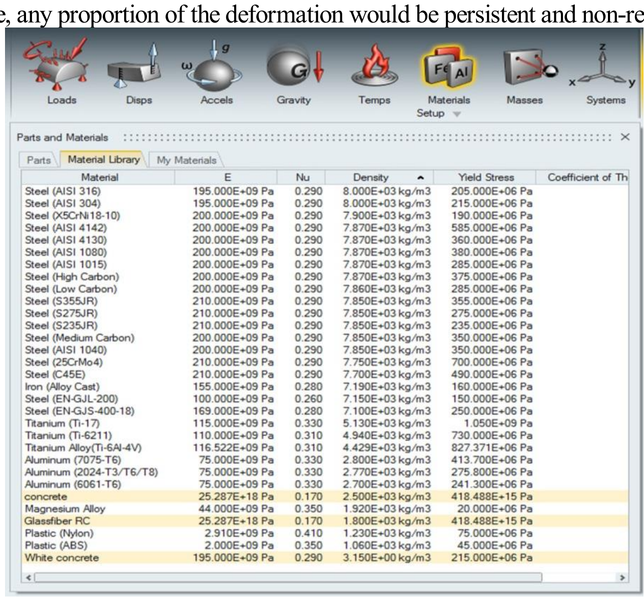


Figure 4: Distribution of Forces and Supports.

9.3. Selection of Materials

In the library of the program's materials, the characteristics of reinforced concrete, white concrete and fiberglass-reinforced concrete, as shown in Fig. 5. Where the input values of material properties are E: Young's Modulus of Elasticity (Young's modulus) or modulus of elasticity is a number which measures the resistance of an object or material to elastic deformity such as non-permanently when a force is applied to it Elastic [15], Poisson's Ratio When a material is compressed in one direction, It always tends to expand in two other directions parallel to the compression direction. This technique is called the Poisson effect. (nu) is a measure of this effect. The Poisson ratio is the expansion fraction separated by the compression fraction [16], in engineering and materials science (Density and Yield Stress) or yield point of a material is defined as the stress at which the material begins to deform plastically. When the tension added is withdrawn, the substance bends elastically before the yield point, and returns to its original shape. After reaching the yield stage, any proportion of the deformation would be persistent and non-reversible [17].



Material	E	Nu	Density	Yield Stress	Coefficient of Th
Steel (AISI 316)	195.000E+09 Pa	0.290	8.000E+03 kg/m3	205.000E+06 Pa	
Steel (AISI 304)	195.000E+09 Pa	0.290	8.000E+03 kg/m3	215.000E+06 Pa	
Steel (X5CrNi18-10)	200.000E+09 Pa	0.290	7.900E+03 kg/m3	190.000E+06 Pa	
Steel (AISI 4142)	200.000E+09 Pa	0.290	7.870E+03 kg/m3	585.000E+06 Pa	
Steel (AISI 4130)	200.000E+09 Pa	0.290	7.870E+03 kg/m3	360.000E+06 Pa	
Steel (AISI 1080)	200.000E+09 Pa	0.290	7.870E+03 kg/m3	380.000E+06 Pa	
Steel (AISI 1015)	200.000E+09 Pa	0.290	7.870E+03 kg/m3	285.000E+06 Pa	
Steel (High Carbon)	200.000E+09 Pa	0.290	7.870E+03 kg/m3	375.000E+06 Pa	
Steel (Low Carbon)	200.000E+09 Pa	0.290	7.860E+03 kg/m3	285.000E+06 Pa	
Steel (S355JR)	210.000E+09 Pa	0.290	7.850E+03 kg/m3	355.000E+06 Pa	
Steel (S275JR)	210.000E+09 Pa	0.290	7.850E+03 kg/m3	275.000E+06 Pa	
Steel (S235JR)	210.000E+09 Pa	0.290	7.850E+03 kg/m3	235.000E+06 Pa	
Steel (Medium Carbon)	200.000E+09 Pa	0.290	7.850E+03 kg/m3	350.000E+06 Pa	
Steel (AISI 1040)	200.000E+09 Pa	0.290	7.850E+03 kg/m3	350.000E+06 Pa	
Steel (25CrMo4)	210.000E+09 Pa	0.290	7.750E+03 kg/m3	700.000E+06 Pa	
Steel (C45E)	210.000E+09 Pa	0.290	7.700E+03 kg/m3	490.000E+06 Pa	
Iron (Alloy Cast)	155.000E+09 Pa	0.280	7.190E+03 kg/m3	160.000E+06 Pa	
Steel (EN-GJL-200)	100.000E+09 Pa	0.260	7.150E+03 kg/m3	150.000E+06 Pa	
Steel (EN-GJS-400-18)	169.000E+09 Pa	0.280	7.100E+03 kg/m3	250.000E+06 Pa	
Titanium (Ti-17)	115.000E+09 Pa	0.330	5.130E+03 kg/m3	1.050E+09 Pa	
Titanium (Ti-6211)	110.000E+09 Pa	0.310	4.940E+03 kg/m3	730.000E+06 Pa	
Titanium Alloy(Ti-6Al-4V)	116.522E+09 Pa	0.310	4.429E+03 kg/m3	827.371E+06 Pa	
Aluminum (7075-T6)	75.000E+09 Pa	0.330	2.800E+03 kg/m3	413.700E+06 Pa	
Aluminum (2024-T3/T6/T8)	75.000E+09 Pa	0.330	2.770E+03 kg/m3	275.800E+06 Pa	
Aluminum (6061-T6)	75.000E+09 Pa	0.330	2.700E+03 kg/m3	241.300E+06 Pa	
concrete	25.287E+18 Pa	0.170	2.500E+03 kg/m3	418.488E+15 Pa	
Magnesium Alloy	44.000E+09 Pa	0.350	1.920E+03 kg/m3	20.000E+06 Pa	
Glassfiber RC	25.287E+18 Pa	0.170	1.800E+03 kg/m3	418.488E+15 Pa	
Plastic (Nylon)	2.910E+09 Pa	0.410	1.230E+03 kg/m3	75.000E+06 Pa	
Plastic (ABS)	2.000E+09 Pa	0.350	1.060E+03 kg/m3	45.000E+06 Pa	
White concrete	195.000E+09 Pa	0.290	3.150E+00 kg/m3	215.000E+06 Pa	

Figure 5: The Library of Program's Materials.

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9.4. Analysis of Compression and Tension

Fig. 6 shows the resulting forces of compression and tension. This enables the allocation of the material where needed by the material characteristics and the forces of acting (metal plates are tension, concrete is compression) at further phases of the design.

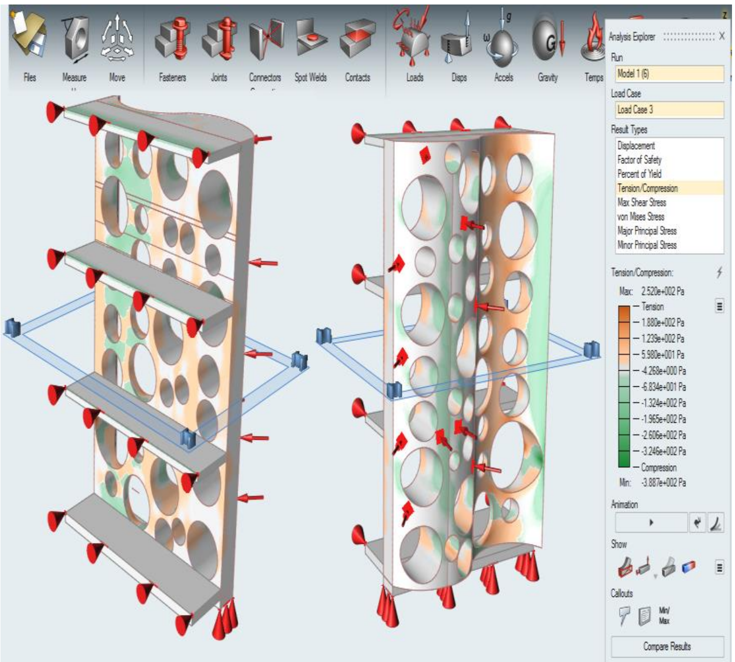

Figure 6: Analysis of Compression and Tension.

10. Results

The following Table 5. summarizes comparative outcomes from the material optimization and structural effectiveness factors of contrast between models generated from solidthinking inspire software and the case study buildings designs and That produces a 3D printed models Which produce forms with a lower density ratio for the materials used, Where we notice after the improvement process, the biggest decrease was in the second case, which is the traditional Reinforced Concrete material, and then comes the first case that used white concrete and the least of the third case, which used Fiberglass Reinforced Concrete material, which indicates that the use of improvement differs from one substance to another, where optimization is at the highest level concerning untreated traditional materials, which leads to a difference in the density of the materials and thus a decrease in cost.

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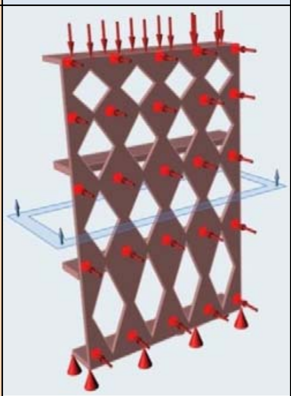
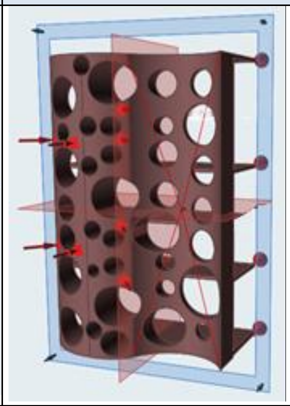
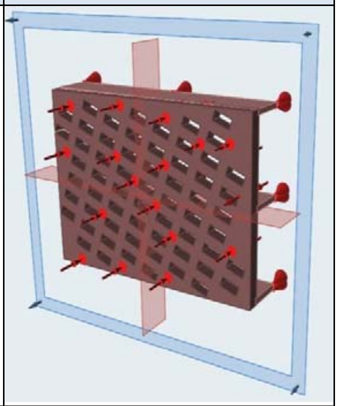
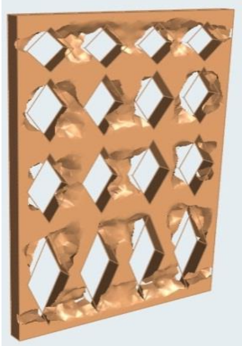
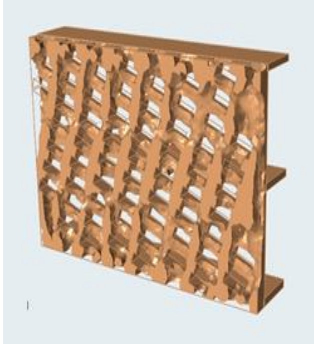
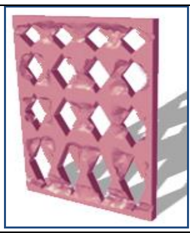
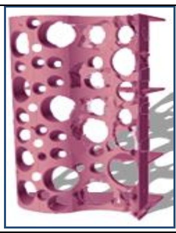
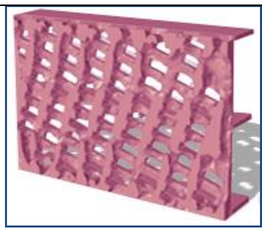
Table 5. Comparison of material and structural efficiency with
The victoria gate, the o-14 building and the broad museum.

	Victoria Gate	**O-14 Folded**	**The Broad Museum**
Model to optimize			
Optimized model by SolidThinking Inspire			
Structural System	Diagrid	Diagrid	Exoskeleton
Skin Material	White Concrete Panels (Density = 3150 kg/m^3)	Reinforced Concrete (Density = 2500 kg/m^3)	Precast Fiberglass Reinforced Concrete Panels (Density = 1800 kg/m^3)
Weight of (7m X 11m) Exterior Load-Bearing wall section before optimization	62 ton	63.525 ton	28.56 ton
Weight of (7m X 11m) Exterior Load-Bearing wall section after optimization	53.514 ton calculation by solidThinking Inspir	45.10 ton calculation by solidThinking Inspir	25.01 ton calculation by solidThinking Inspire
A 3D Printed model			
Average reduced percentage of material	The percentage of Weight reduce to **13.7%**	The percentage of Weight reduce to **29%**	The percentage of Weight reduced to **12.4%**

The improvement aimed to maximize hardness to obtain the lowest material density and thus the lowest cost while preserving the shape and preventing deformation. The optimization of the structural wall provides mechanical properties as designed with the parameter (maximum deviation hardness) where a structure weighs 18.36% less than similar cases before optimization, Where in the first case, the rate decreased from 62 ton to 53.514 ton by 13.7 percent, In the second case, the rate decreased by 29 percent from 63,525 ton to 45.10 ton and In the third case, it decreased by 12.4 percent from 28.56 ton to 25.01 ton As shown in Fig. 7.

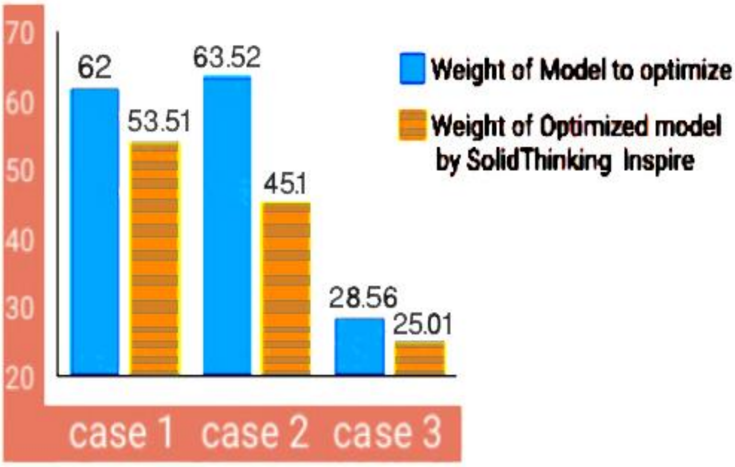


Figure 7: Reduce Weight of Load-Bearing Wall after Process Optimization.

The model input parameters (design volume, materials, and loading conditions) interact as they affect each other. Integral systems are inseparable and are given a direct integration result it is possible to produce shapes with distributed loads directly related to the shape and materials used which is the aim of this study.

4. Conclusion

The use of algorithms enables the creation of a wide range of solutions characterized by speed and effortlessly, in addition to allowing the development of different design methods.
Application of mechanically integrated behavior in the early stages of architectural design on the load-bearing wall, to build its material and structural efficiency, the strategy used to solve the problem is It is a method of integrating each of the known parameters such as load cases, supports, design volume and Materials:

- Structural wall skin is modeled and created using a topology optimization algorithm using software (solidthinking inspire).
- Model size constraints for the Maximum 3D printing machine are 14 x 22 cm, accordingly and to maintain a scale of (1:50); a 7 x 11 m portion of the structural skin was examined during the experimental study.
- The optimization on the structural wall skin of mechanical properties provides a structure which is 18.36 percent less in weight than the comparable cases.
- The use of algorithm programs to improve materials has a Clear on the relationship between form and functionality. As for the improvement of conventional reinforced concrete, it resulted in lower density, hardness and better surface quality than white concrete, followed by fiberglass-reinforced concrete. Conventional reinforced concrete can be used to build lightweight structures after improvement which is more structurally functional.

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