Nexo Revista Científica
Vol. 36, No. 05 (Especial), pp. 51-62/Noviembre 2023
ISSN-E 1995-9516
Universidad Nacional de Ingeniería

http://revistas.uni.edu.ni/index.php/Nexo
http://dx.doi.org/10.5377/nexo.vXXiXX.XXXX

Rumbo a la construcción sostenible por medio de la madera y el diseño paramétrico: aplicaciones y resultados

Towards sustainable construction through timber and parametric design: applications and results

Mauricio Díaz Valdés [1, *], María Fernanda Martínez González [2], Leonardo Geremia [3]

[1] Universidad Politécnica de Cataluña. Barcelona, España.
*mdiaz@acier.com.mx.
[2] Universidad Nacional Autónoma de México. Ciudad de México, México.
arq.fernanda.mg@gmail.com
[3] Facultad de arquitectura, planeamiento y diseño. Universidad Nacional del Rosario, Rosario, Argentina
leonardo.geremia92@gmail.com

(recibido/received: 07-junio-2023; aceptado/accepted: 17-septiembre-2023)

RESUMEN

Actualmente las ciudades y la construcción serán claves para el desarrollo sostenible ya que hoy día cerca del 60% de la población vive en ciudades y se espera que para el 2040 la cifra aumente al 75%; por otra parte, el sector de la construcción se encarga de generar cerca del 35% de las emisiones de CO2 lo cual lo convierte en uno de los sectores más contaminantes. Según estudios realizados por la O.N.U. a nivel mundial las ciudades ocupan solo el 3% de la tierra, pero representan cerca del 60% del consumo de energía y de recursos naturales. Esto conlleva que durante las próximas décadas la construcción deberá de enfrentar muchos problemas y deberá adaptarse ante las adversidades actuales. Es así que la tecnología, los materiales y la innovación serán catalizadores para poder tratar de mitigar los efectos del cambio climático. Esta investigación se realizó con una perspectiva de diferentes disciplinas, tales como: ecología, biología, ingeniería, arquitectura esto para obtener un mejor resultado y de esta manera afrontar el cambio climático; fue así que concluimos como el uso de la madera y el diseño paramétrico pueden ser una opción para modificar las practicas del sector de la construcción y que tienen un futuro positivo en el devenir de la arquitectura. Por medio de la presentación de una estructura ligera se va analizar los resultados sostenibles que presentan la madera y el diseño paramétrico.

Palabras claves: Cambio climático, sostenibilidad, agenda 2030, madera, diseño paramétrico, materiales sostenibles.

ABSTRACT

Cities and construction are currently catalysts for sustainable development since today close to 60% of the population lives in cities and it is expected that by 2040 the figure will increase to 75%; On the other hand, the construction sector is responsible for generating about 35% of CO2 emissions, which makes it one of the most polluting sectors. According to studies carried out by the U.N. Globally, cities occupy only 3% of the land, but represent close to 60% of the consumption of energy and natural resources. This implies that during the next decades construction will have to face many problems and will have to adapt to current adversities. Thus, technology, materials and innovation will be catalysts in order to try to mitigate the effects

of climate change. This research was carried out with a perspective of different disciplines, such as: ecology, biology, engineering, architecture, this to obtain a better result and thus face climate change; It was thus that we concluded how the use of timber, parametric design and software can be an option to modify the practices of the construction sector and that they have a positive future in the future of architecture. Through the presentation of a light structure, the sustainable results presented by timber and parametric design will be analyzed.

Keywords: Climate change, sustainability, 2030 agenda, timber, parametric design, sustainable materia**1.**

1. INTRODUCTION

The current period that humanity is going through is unique in the history of civilization since we face great problems, such as: overpopulation, climate change, migration, excess CO2 emissions and excessive consumption of natural resources. These are examples that should motivate actions and direct them to solve them for the well-being of humanity. According to the UN Bulletin on Greenhouse Gases 2022, it states that the CO2 emissions figures continue to rise (Figure 1), which is worrying and shows that very few actions are being taken to address this problem and that if we seek to meet the objectives of the UN 2030 Agenda, we must increase practices and knowledge to mitigate the effects of climate change.

For its part, steel, cement and glass are the materials most used by the construction sector and are the materials that pollute the most in the world. It is estimated that cement generates about 23% of CO2 emissions and unfortunately its manufacture entails excessive use of natural materials and energy consumption; It is estimated that after water, cement is the material that humanity uses the most. Other materials such as steel and glass are materials that are highly polluting and their production generates about 19% of CO2 emissions into the environment. This should motivate to change the practices of these materials. The foregoing is summed up by the fact that we are in the second decade of this century and we have an uncomfortable reality, we cannot continue building as it was done in the last century, our practices and ways of building must change.

In UN Secretary Cities and Climate Change, Michael R. Bloomberg explains that “the steps that cities take now to combat climate change will have a great impact on the future of our planet. The cities have shown that they have the capacity and the will to face this challenge”; denoting that cities are catalysts for the construction sector to mitigate the effects of climate change. In this way, cities play an important role in mitigating the effects of climate change, since from the year 2030 it is expected that a New York City will be built every month; the population is expected to increase by a further 20% by 2030. Cities should promote sustainable construction and this goal will only be achieved by introducing new ways of building.

This research in order to propose how technology, timber and parametric design can be a great example of how to mitigate the effects of climate change. After reviewing the "state of the art", analysis and figures regarding climate change, we managed to generate a multidisciplinary investigation in order to cover different problems and face the same solution. The future of architecture focuses on how to develop new proposals that integrate environmentally friendly materials, the use of technologies and a critical sense in the design process.

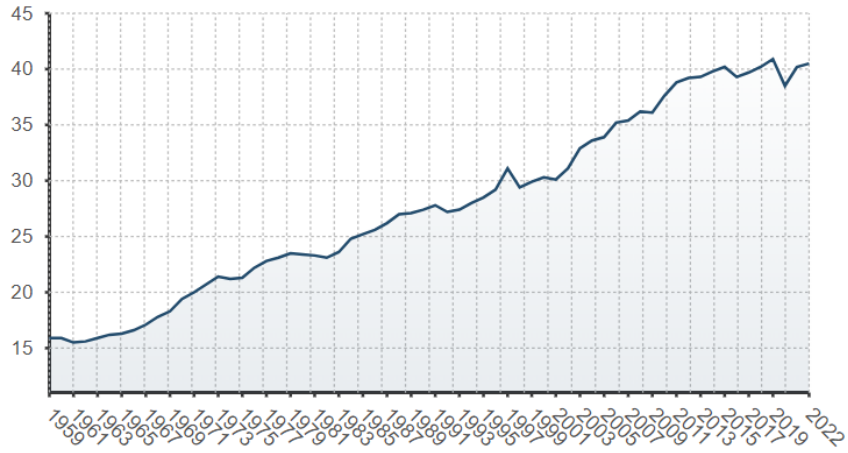

Figure 1. Unfortunately, CO2 emissions continue to rise, during 2020 they decreased due to COVID-19, but after this the figures increased and are expected to rise in the coming years; By the year 2022, about 40.2 tons of CO2 were produced into the environment. The impressive about the graph is that in less than a decade we have tripled CO2 emissions into the environment
. Source: Global Carbon Project

2. RESEARCH OBJECTIVES

The main objective of this article is to present in a clear and concise way how it can be built sustainably through timber and the use of parametric design and to give a global overview of the situation that architecture is going through and the effects that construction has. in the environment. The research seeks to link the relationships that exist between climate change, materials, technology, parametric design and sustainable development to apply it to current crises. The investigation begins by analyzing the world statistics that integrate climate change and the construction sector and after this, it seeks to generate a response to the problem studied and concludes with the presentation one light weight timber structure carried out that yield positive data on how it can be built sustainably and generate a positive effect for construction.

3. THE RELATIONSHIP BETWEEN SUSTAINABILITY AND TECHNOLOGY IN THE FACE OF CURRENT ADVERSITIES

At the end of the last century, the word sustainability had greater relevance than had ever been seen in the past and thus became a central theme of architecture. Today it is a reality that sustainability must be linked to construction, design, engineering and architecture; Sustainability and climate change are concepts of global interest that will mark this century. Under this context that humanity is going through, future constructions and designs must seek to solve problems through innovative, sustainable and technological solutions. Referring to the above, the Secretary General of the U.N. Antonio Guterres affirms that: "technology is on our side to mitigate the effects of climate change"; Thus, thanks to all the advances that we currently have, we must know how to take advantage of them in order to be able to build in an innovative and sustainable way. The idea of sustainable development was the first step to integrate various scientific fields and the integrity of people interested in the future of our planet. It was a shift towards interdisciplinarity in science and revision of the relationship between man, Nature and Technology (Januszkiewicz, K, 2019).

The new scope that we have today thanks to new technologies develops a new perception of the resources and needs that this sector demands. Currently, the mentality within the design process introduces the search for sustainable materials and the use of technologies, which allows a lower impact on the environment; Due to the above, during the last two decades, it has been decided to integrate sustainable materials and take advantage of software; actions that previous centuries had never been seen and that today are having a positive effect on architectural design.

To promote the effects of sustainability and apply the new designs, we must take the city as the setting in order to try to mitigate the effects of climate change; cities always promote social and technological development; but on the other hand, the misapplication of laws or regulations can promote negative effects in the face of current adversities. The U.N. affirms that cities are "catalysts" to be able to mitigate the effects of climate change since they currently contain 60% of the world's population and with statistics indicating that this number continues to increase. One of the key issues for sustainable development according to the U.N. is the integration of new technologies and sustainable materials that allow minimizing CO2 emissions into the environment. It is thus that the way in which cities are built during the following years will be crucial for the prosperity of humanity.

4. TIMBER, PARAMETRIC DESIGN AND ITS CONTRIBUTION TO SUSTAINABLE DESIGN

In the present that we are going through, it forces architects to redefine their practices and designs; The global profile of the architect must contain a completely multidisciplinary perspective in order to be able to generate better results and options. Thus, technology, parametric design and knowledge of materials are tools of great current value for the profession of the architect; During the last decades, technological advances and the application of sustainable materials have increased because they present great solutions for a sustainable future. In order to respond to these needs we must build and promote sustainable development through new approaches and solutions and in parallel integrate new building materials and integrate technology in the best way. The designers, as never before, are facing new technologies developed in the search for new materials based, among others, on wood components and the improvement of manufacturing methods at the same time. In this process, the material and manufacturing technology adjustment to desired aesthetic outcomes is possible not only by the material used but also by the self-organization of the structure’s optimization (Stefańska, A, 2021).

Today more than ever construction materials have an important role in construction since at the time of construction they must be chosen in order to be sustainable, optimal and economical; the construction materials used in the coming years should promote zero carbon construction. Unfortunately, the manufacture of many materials currently generates many CO2 emissions (Figure 2) to the environment, which is why timber is gaining ground in the construction sector.

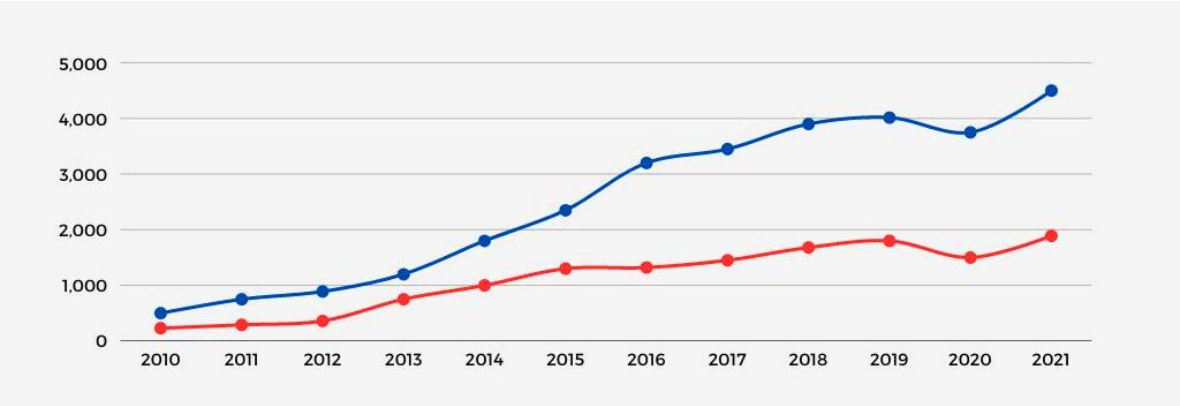

Figure 2. The global production of cement (blue) and steel (red) has grown exponentially during the last decade, unfortunately the millions of metric tons emitted by these materials place them as unsustainable materials.

4.1 RE-ADAPTING TIMBER STRUCTURES

In the course of the 20th century, timber construction started to diverge. On the one hand, technological advancements allowed to transform wood into better performing engineered materials (Aleksandra, A, 2018). One of the questions that marks this century is: what is the best way to combat the CO2 emissions generated by construction? The answer lies in choosing intelligently the materials we use to build. Currently the construction sector is dominated by the use of cement and steel; both industries are among the most polluting in the world; These industries are in a period of change as they are seeking to manufacture these materials without consuming so many natural resources and without generating so many CO2 emissions (Figure 3). Unfortunately, this goal is going very slowly and they are still generating a lot of CO2 emissions into the environment; This puts into debate how we are going to use the materials during the following decades. Taking into account that the population will increase and that it will be necessary to build much more than what had been built, we must know what materials we will use in order to build sustainably.

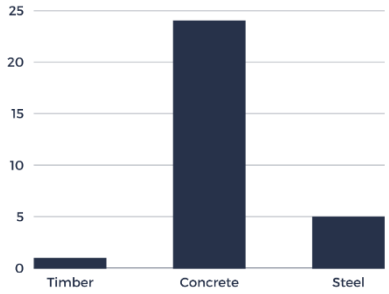

Figure 3. Energy used to produce 1 ton of each material; in the case of the concrete for making one ton of this material it is 24 for more times than timber; the steel has a similar difference with five more tones than timber.

Timber is a highly sustainable biomaterial since it has great mechanical, economic and sustainable properties; this has made it one of the favorite biomaterials during the last decades. For many centuries this

material was one of the pioneers in construction, after the Industrial Revolution the construction processes changed; but thanks to technological advances and digital fabrication, this material is generating new ideas and projects that are highly sustainable; On the other hand, timber is one of the most important renewable materials for sustainable construction since timber is responsible for absorbing CO2 and converts it into oxygen through photosynthesis and solar energy.

Worldwide, the timber industry has enjoyed a great increase in its applications and uses in the architecture sector since globally it presents great economic, mechanical and sustainable contributions when compared to other materials. Throughout history, timber has always been a catalyst for innovation and currently has a very promising future. In various parts of the world, this material is demonstrating great sustainable capabilities and through parametric design and the application of innovations in technology, proposals are being generated that potentiate innovation and sustainability. Thanks to the advantages offered by this material, its popularity has increased since, apart from building in a sustainable way, it is responsible for providing futuristic and avant-garde designs and thus denote great potential focused on structural and sustainable performance.

4.2 ABOUT THE PARAMETRIC DESIGN

Parametric design is not unfamiliar territory for architects. From ancient pyramids to contemporary institutions, buildings have been designed and constructed in relationship to a variety of changing forces, including climate, technology, use, character, setting, culture, and mood. The computer did not invent parametric design, nor did it redefine architecture or the profession; it did provide a valuable tool that has since enabled architects to design and construct innovative buildings with more exacting qualitative and quantitative conditions (Phillips, S, 2010).

During the last 15 years, both architects and engineers have integrated new 3D design and modeling tools and the use of these new tools continues to rise exponentially; since by means of this way it can be designed in an innovative way and goes beyond the limits of the profession. It is so that today the digital language, software and 3D modeling promote sustainable development and this provides new tools to the architect (Figure 4). Therefore, parametric design offers great opportunities to optimize any design more effectively, this means optimizing projects which translates into lower cost, less material and much lower CO2 emissions.

The architectural design process has changed during the last decades through parametric design since architects are in charge of developing designs and through parameters the program offers innovative and unique solutions. Apart from its sustainable advantages, parametric design can help to minimize the amount of time spent in the design process and on the other hand provides different design variables which adapt to the needs of the project. The novelty of parametric design is that it integrates structural, material and economic concepts, which favors sustainable design.

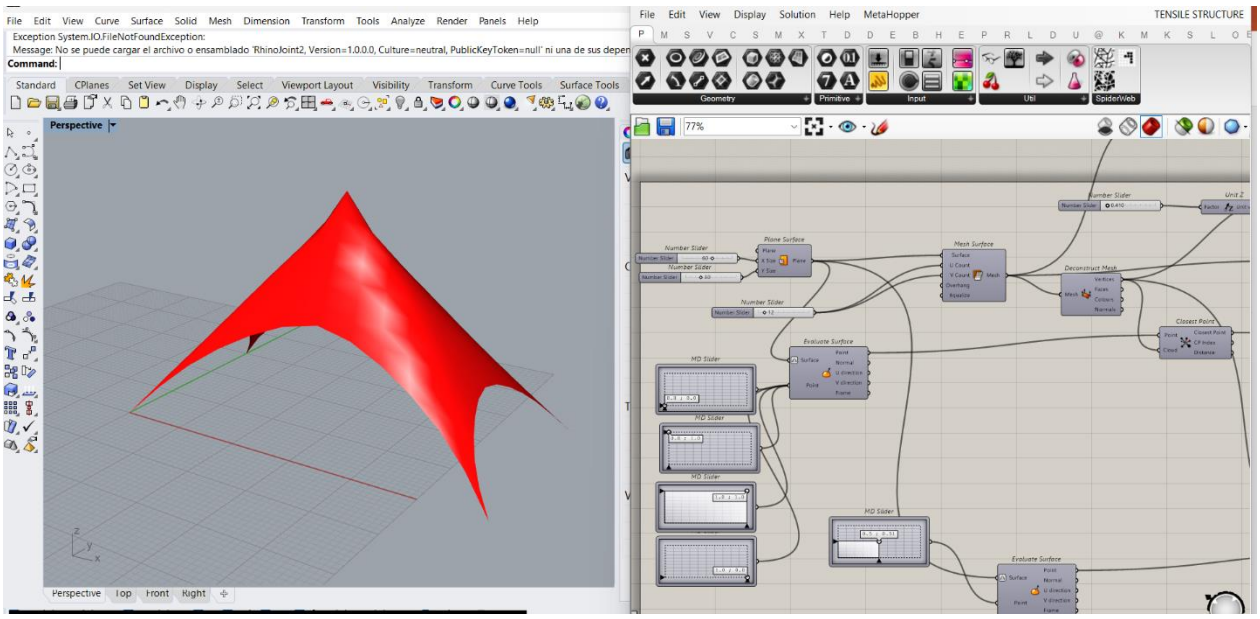

Figure 4. Grasshopper is a software for algorithmic design, within this you would find parametric and generative design with Grasshopper, which contains a set of tools (which are getting bigger and bigger) that allow you to design custom algorithms for your company's workflows or a particular project. Grasshopper is a plugin within the Rhinoceros software, which is specialized software for 3D. Source: Mauricio Díaz Valdés

5. CASE OF STUDY

Today, thanks to technology, materials and the goal of building more with less, the way in which it is built has changed exponentially during the last decades. Thus, the ability to transform shapes has been greatly influenced by manufacturing methods, technology, materials, and this allows for a new way of building like never before. Through the Rhino program and the Grasshopper plug-in, parametric design was used to carry out this structure, so through the software we concluded the development of a lightweight structure that has a maximum height of 3.5 meters in the highest part and It has a distance of 9 meters between each support point (Figure 5). The timber that was used were pieces of plywood with 1" x 6" wide stockings, the manufacture of this structure was carried out within the university facilities and was transported to the province of Alp.

For the development and optimization of this structure we chose to use different parametric design tools in order to obtain the best result. It was so that after several proposals and prototypes you develop a structure with a double layer, which has the purpose of giving it greater rigidity and covering greater distances with less material; which makes it a highly innovative and sustainable structure. The unions of each of the pieces of timber were made (Figure 7) of galvanized screws and nuts in each of the unions, in this way the pieces are joined together and give it much greater rigidity.

New developments in computational design and digital fabrication currently lead to a rethinking of architectural design and delivery processes. In contrast to traditional, hierarchical, and form-driven design approaches, integrative strategies can activate discipline-specific knowledge in early design stages (Menges, A, 2015). The structure that was built was carried out in the province of Alp, Spain, approximately two hours from Barcelona, the light structure was the result of the investigation of different students of the Master in parametric design in architecture of the Universidad Politénica de Cataluña. in the year 2022.

Timber gridshell structure is a efficient structural system, which gains its strength and stiffness through its double curvature and covers large-span space with relatively small amount of materials. However, the future of double curved surface result in complexity of design, analysis, fabrication and construction which leads to the limitation of practical application of timber gridshell (Jin, J,2018).

Total covered area	35m2
Height	3.3 meters
Amount of timber used	380 timbers pieces
Total of days of fabrication and assembly	10 days
Location	Alp, Spain

Table 1 General specifications of the light weight timber structure that was manufactured

Figure 5. Main view of the timber structure which has a PVC cover and has two layers of wood in different directions. Thanks to the double curvature it was possible to obtain much greater rigidity and resistance. Source: Andrés Flajszer

Figure 6. Interior view of the structure, you can see the joints which were by means of a stainless-steel screw and by means of the parametric design the interior triangles were formed in order to give it greater rigidity. Source: Andrés Flajszer

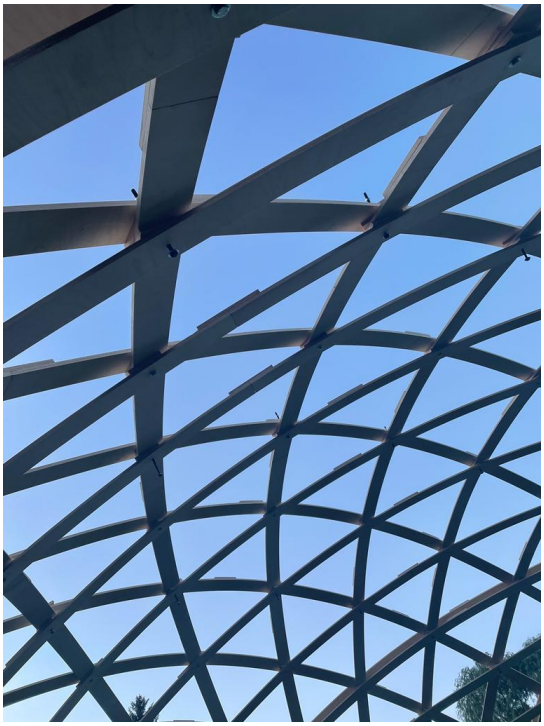

Figure 7. Nuts and bolts were galvanized and assembled on site. Inside the structure you can see the triangular shapes which help to better optimize the structure. Source: Mauricio Díaz Valdés

Figure 8. For the manufacture of the PVC membrane, the measurement was obtained through the program and after that it was ordered to be manufactured, which gave it an accuracy to assemble all the screws, tensioners and stainless-steel cables. This promotes digital manufacturing and computational design as a highly competitive and innovative tool. Source: Mauricio Díaz Valdés

6. RESULTS AND DISCUSSION

The uncomfortable truth that we are currently facing is highly related to technological advances, the development of knowledge and experimentation with sustainable materials, and it will be in this way that we will be able to face current emergencies. Currently we must encourage reflection and creativity to build in a way in which we have never built before; The construction systems and construction models that were used during the last two centuries made great contributions to their time, but unfortunately, they did not count on the awareness of the abuse of natural resources. Currently worldwide due to pressure to try to mitigate the effects of climate change, all disciplines are focusing their purposes to combat this problem. Regarding this, the construction sector has a lot of responsibility and skills to reconfigure future scenarios; that is why during the last decades it has acquired a crucial role in decision-making when designing.

The negative effects of climate change regarding construction were presented in this research which explained that the construction sector consumes too many natural resources and generates a lot of CO2 emissions. Therefore, it is a reality that the construction industry is one of the least sustainable and must change the way of building during the coming decades. However, as analyzed, there are several options to build sustainably, taking advantage of technological advances and sustainable materials; Therefore, the way

in which it will be built in the coming decades will be affected by the use and optimization of technology and materials.

The light weight timber structure that we manufacture presents great advantages compared to conventional structural systems, since when compared with these materials, CO2 emissions are very different. In this sense of production, manufacturing and design, this structure presents great technological and innovative advantages. but the most important advantage is that it promotes sustainable development. The increase in light construction has shown great advantages against common construction since it provides key points for sustainable development, since through ecological materials such as timber it presents greater advantages against steel and cement; The structure that we develop presents better advantages and opportunities since it can be built quickly, economically and by integrating the software. An important aspect is that building with timber is not the solution against the effects of climate change, the real answer lies in using the materials optimally and intelligently to establish the design criteria and the emissions that production and production generate into the environment. Manufacture of materials used in the project. This research revealed how parametric design and timber can be a great option to mitigate the effects of climate change, demonstrating that software knowledge can be great tools for the architect and that they positively benefit the result and emissions of CO2.

The importance of integrating these technologies and ways of building is very important to integrate them into cities in the coming decades; Through experimental pavilions, these proposals can be integrated into the buildings of the cities in the coming years. Today there are already skyscrapers, houses and different buildings that are choosing to use timber intelligently and optimally; Thus, the development of these construction techniques and their inclusion in cities will be crucial for the sustainable development of cities.

We must understand that the period we are going through is a period of adaptation in which the actions we carry out will be crucial for the construction sector and must be focused on mitigating climate change. More precisely, the goal of this century is to build sustainably, but to build in this way we must know that it involves different concepts, techniques and methods. Today and in the future of architecture, parametric design and timber are giving engineers and architects a new perspective and are benefiting projects; Thus, technology motivates reflection regarding the design process since new methodologies are developed that are applied to the final project. On the other hand, the integration of sustainable materials, technology and digital fabrication are important keys to achieve the goal of building sustainably.

7. ACKNOWLEDGMENTS

The development of the light structure was carried out by all the students at the master degree in parametric design in architecture (MPDA) of the 2021-2022 generation, all the students of the generation took care of the design and manufacture of it. The images were taken by Andrés Flajszer after the construction of the light structure. We thank Enrique Soriano, Gerard Bertomeu and Pep Tornabell who are the organizers of the master.

8. REFERENCES

Aleksandra, A. (2018). Complex Timber Structures from Simple Elements Computational Design of Novel Bar Structures for Robotic Fabrication and Assembly, Zürich, Switzerland: ETH Zürich Research Collection

Januszkiewicz, K (2019), Climate Change Oriented Design – Learning from Nature – Nature and Advanced Technology, 4th International Symposium on Innovative Approaches in Architecture, Planning and Design, 187-193

Jinxi, J, Han, L, Chai, H, Zhang, X, (2018) Digital design and construction of lightweight steel-timber composite gridshell for large span roof.

Krieg, Oliver & Schwinn, Tobias & Menges, Achim & Li, Jian-Min & Knippers, Jan & Schmitt, Annette & Schwieger, Volker. (2015). Biomimetic Lightweight Timber Plate Shells: Computational Integration of Robotic Fabrication, Architectural Geometry and Structural Design.

Stefańska1, A., Cygan M., Batte K. (2021), Applications of Timber and Wood-based Materials in Architectural Design using Multi-objective Optimisation Tools. Construction Economics and Building. Vol. 21, (No. 3), 105-121

Phillips, S. (2010) Parametric design: a brief history. ArcCA: The journal of the American Institute of Architects. Vol 1, pp-24-29

8. PROFILE OF THE AUTHORS

Mauricio Díaz Valdés is an architect, technologist, lecturer and researcher and his research focuses on seeking and finding the new ways of designing through the sustainability, architecture and engineering with a multidisciplinary perspective that integrates sustainable materials, digital fabrication, structural optimization and 3D modeling. He holds a Master in Architecture from the Universidad Nacional Autonóma de México (UNAM) and another Master in Parametric Design (MPDA) by Universidad Politénica de Cataluña in Barcelona, Spain in Barcelona, Spain.

Maria Fernanda Martínez González; graduated with a degree in Architecture from the National Autonomous University of Mexico, she completed her master studies at Universidad Nacional Autonóma de México (UNAM), with a master's degree in Architectural Design, she has developed lines of research for the application of technological development in habitability, building management through the inmotica and the consequence in the perception in the user.

Leonardo Geremia is an architect from the National University of Rosario, Argentina, and has a master's degree in Parametric Design in Architecture from Universidad Politénica de Cataluña in Barcelona, Spain. He is a qualified teacher in the areas of Theory and Technique of the Architectural Project, Theory and Technique of Design, History of Architecture and Art, and in Basic Sciences at the National University of Rosario; having carried out tasks in the subjects History of Architecture I and II, Graphic Expression I and II, Computer Assisted Design, and Mathematics, belonging to the basic cycle of the curriculum, and Architectural Project II, of the 5th year, for more than seven years.