TECHNOLOGIES COMPATIBLE TO CLIMATE CHANGE AS A STRATEGY IN THE FIELD OF ARCHITECTURE

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***Abstract* — Temperature change is one of the most important factors for determining the effects of climate change in urban areas. In the coming years, the planet is going to become even more sensitive to climate change. For this reason, it is essential to find a technological answer to climate change for building design. The question arises: do such climate-compatible technologies already exist which can be used as a strategy for the design of resilient building envelopes? The aim of this research is to describe technology which is compatible with climate change when applied to buildings in urban areas. This study consists of the application of statistical analysis to design an evaluative technological matrix. The product was the verification of a hypothesis through a basic simulation in order to evaluate the technological processes which are compatible with climate change. This new model will be a very useful tool in the design stages of buildings because they take into account climate change in urban areas.**

Keywords — Technological change, global warming, architectural design, urban design.

I. INTRODUCTION

Temperature change in buildings is one of the most important factors for determining the effects of climate change in urban areas. In the next few years, for instance, Bogotá and neighbouring regions will be more sensitive to temperature change and consequently the comfort of urban zones throughout the country will be considerably affected. Government institutions believe that the temperature will increase from 2 to 4 degrees centigrade in the next 80 years [1].

One way of successfully reducing these type of events is to design resilient buildings, which means that they are sensitive to the climate [2]. Effectively, a resilient building is characterised by having the ability to absorb different changes caused by extreme weather events. For example, controlling exterior temperature change and self-regulating interior temperature. Such a building would also be able to bear the impact of a flood caused by heavy rainfall and it would be able to function again soon after the disaster.

This might mean that it continues to function even when certain parts of the of the building fail. A building's resilience can be measured and determined using eight key characteristics. These variables as: robustness, redundancy, ingenuity, speed, capacity, flexibility, tolerance and cohesion.

It should be noted that the two concepts, resilience and sustainability, are not the same. A resilient building is not necessarily sustainable and vice versa. Consequently, today, building design is becoming a complex task because there are increasingly more sustainability requirements which must be satisfied. In addition to this it must be resilient to the climate. This is why it is important to highlight the role played by building envelopes when dealing with climate change.

Recent investigations have focused on the design of building envelopes which respond or adapt to the climate and offer great advantages over the designs of conventional facades [3], [4]. In this respect, great importance has been given to studying the thermal efficiency of a building envelope, which has lead to the lower consumption of energy in buildings. However, it has become apparent in recent years that it is impossible for energy efficient buildings to focus solely on the U-value of a building [4]. An analysis of the relationship between the thermal envelope and other variables is also required so as to identify the extent of its importance and it is behaviour with respect to the climate.

Some authors [5] pose the need for an integrated approach to building design which considers the possible associations between the resilience and sustainability of a building, through technology. The reality is that natural disasters which have occurred over the last quarter of a century have proved themselves not to be lineal problems that can be resolved in isolation. Rather, technology plays an important role in the design process in order to create an integral solution to them.

Today, buildings are susceptible to extreme climate events such as floods, extreme rainfall and fierce heat waves. These types of events do not just affect the building itself, but also its design, construction and operation. For example, heat waves affect the building processes in the construction industry in the United Kingdom [6]. In this case the design, construction and operation processes have each suffered due to adverse weather conditions. These examples, when applied to tropical countries, demonstrate how essential it is to identify the relationships between the different requirements for the design and construction of buildings.

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Doing so should mean avoiding such inconveniences in the future which make these processes inefficient.

Global climate patterns have also created a pressing need to measure and improve the resilience of building materials. With respect to other countries, current methods used to define and evaluate resilience in Colombia are incoherent, difficult to apply and lack systemisation. This has resulted in varying class standards to quantify the value of resilience in buildings [7].

In this respect, the documentary review consulted in this study has looked at the application of different materials, including a variety of new materials which could be utilised as resilient reinvestment for buildings and urban areas [8]. Therefore, technology becomes an important factor when designing a building generally, and particularly the building envelope. It is important to point out that when we talk of technology we are referring to the life cycle of a building, which is split into three parts: design, construction and operation. It is crucial to study the relationship between CO2 emissions, heat insulation, energy efficiency, efficient consumption of resources, material and the control of outside temperature, at each of these three stages.

Therefore, it is necessary to find a technological answer to climate change for the design of resilient building envelopes. It's worth asking, are there existing technologies which are compatible with climate change as a strategy for the design of resilient building envelopes? The aim of this research is to describe the concept of technology which is compatible with climate change and the resilience of said technologies when applied to building envelopes in urban areas. The hypothesis of this research was as follows:

Levels of CO2 emissions should be less than or equal to the control that insulating material has in a building envelope. In turn, the effectiveness of the insulating material is equal to the energy efficiency of the building. The energy efficiency should be less than or equal to the application of strategies for efficient consumption of resources during the construction of said building, and in turn, the efficient consumption of resources must be less than or equal to the application of resilient materials. Therefore, the application of resilient materials in order to build good heat insulation in a building must be greater than or equal to the external temperature control to in the building envelope.

This hypothesis can be expressed using the following mathematical formula:

$$Ho = [(F1 \leq F2) \cup (F2 = F3) \cup (F3 = F4) \cup (F4 \leq F5) \cup (F5 \geq F6)]$$

This study consisted of, in the first instance, building the concept of technology which is compatible with climate change and the application of statistical analysis in order to design an analysis matrix of the study variables. This was then proved using a basic simulation model which evaluates the application of said technology in building envelopes. This new model will be a useful tool for building design processes that consider the effects of climate change in urban areas. Finally, the structure of this article is as follows: First, the developed methodology and the steps taken to achieve the objective will be explained. Second, the results will be put forward. Third, the discussion will be exposed. Finally, the conclusions and recommendations of the article will be presented.

II. METODOLOGY

First, a review of articles was carried out using a scientific database from which it was found that there are 156 relevant references about this topic. In an initial selection, 80 references were identified and 7 study factors established in order to identify the concept of climate-compatible technology. These factors were:

- Resilience: 9 references were found relating to this concept.
- Low-carbon technologies: 13 references were found relating to this concept.
- Climate-resilient technologies: 12 references were found relating to this concept
- Clean technologies: 12 references were found relating to this concept
- Mitigation strategies: 12 references were found relating to this concept
- Technological strategies: 10 references were found relating to this concept
- Adaptation strategies: 12 references were found relating to this concept

36 references were ultimately selected from which the theory was built for climate-compatible technology. The elaboration of this framework allowed for relationships to be established within the selected factors. To verify the proposed hypothesis a multivariable matrix was designed. Resilience acted as an independent element and 6 other factors acted as dependent elements. The intersection of the 6 independent factors built the matrix.

The proposed methodology focused its analysis on the relationships and characteristics between the dependent factors: low-carbon technologies, climate resilient technologies, clean technologies, mitigation strategies, technological strategies and adaptation strategies. Through the matrix, the relationship and effect that each one of these factors has on a building envelope was determined.

The following variables were then selected as verification variables: 1) Factor 1 - low-carbon technologies: level of CO2 emissions. 2) Factor 2 - climate-resilient technologies: insulating material. 3) Factor 3 - clean technologies: energy efficiency. 4) Factor 4 - mitigation strategies: efficient consumption of resources. 5) Factor 5 - technological strategies - material. 6) Factor 6 - adaptation strategies: external temperature control (see table 1).

A simulation was carried out to test and validate the hypothesis. The parameters of quantitative-qualitative variables were established and given a score from 1 to 5. The values considered at this initial work stage were all positive whole numbers. Random values were used as input variables to prove the hypothesis, obtained from a random mathematical function that feeds back a number larger than zero and less than 1. So that the given number was within the correct range, it was first multiplied by 5 and then 1 was subtracted, in order to remain in the area interval on the graph. This is known as the Markov chain.

The scores were then defined as either poor, fine, good or very good. In accordance with the reviewed literature, a range was established which allowed every variable in the different levels proposed to be evaluated (see table 2). Next, the simulation was carried out. To do so, this model was tested 10 times and it was followed by a basic statistical analysis from which the mean, the median and the mode were extracted. The aim of this was to determine a tendency and identify the cross-section of variables.

TABLE I. MULTIVARIABLE MATRIX.

(A) Climate-compatible technology

		(E) Mitigation strategy (Factor 4)	(F) Technology strategy (Factor 5)	(G) Adaptation strategy (Factor 6)
Item	**Variable**	Efficient consumption of resources	Material	External temperature control
(B) Low-carbon technologies (Factor 1)	Level of CO2 emissions	(B, E)	(B, F)	(B, G)
(C) Climate resilient technologies (Factor 2)	Heat insulation in the building envelope	(C, E)	(C, F)	(C, G)
(D) Clean technologies (Factor 3)	Energy efficiency	(D, E)	(D, F)	(D, G)

TABLE II. VARIABLE EVALUATION TABLE.

(A) Climate compatible technology

Factor	(B) Low-carbon technologies (Factor 1)	(C) Responsive technologies (Factor 2)	(D) Clean technologies (Factor 3)	(E) Mitigation strategy (Factor 4)	(F) Technology strategy (Factor 5)	(G) Adaptation strategy (Factor 6)
Variable	Level of CO2 emissions	Heat insulation in Buildings	Energy efficiency	Efficient resource consumption	Material	Control of external temperature
Bad (1-2)	1,0	2,0	1,0	1,0	2,0	1,0
Fine (2-3)	2,0	3,0	2,0	2,0	3,0	2,0
Good (3-4)	3,0	4,0	3,0	3,0	4,0	3,0
Very good (4-5)	4,0	5,0	4,0	4,0	5,0	4,0

III. RESULTS

The results of the simulation were as follows (see table 3):

- Of the six identified variables, four were classified as 'very good', these were: control of external temperature with 30%, followed by the variables CO2 emissions and energy efficiency with 20% and finally, efficient consumption of resources with 10%.
- With regards to the 'good' variables, efficient consumption of resources and material obtained 40% while insulating materials and temperature control obtained 30%. These were followed by energy efficiency with 20% and finally the level of CO2 emissions with 10%.
- 'Regular': the variable efficient consumption of resources obtained 40%, followed by material with 30%, then heat insulation with 10%. CO2 emissions did not register any results.
- Finally, those classified as 'bad': CO2 emissions obtained 70%, while heat insulation 60% followed by energy efficiency with 40%. At the same time the variable material obtained 30%, external temperature control 20% and finally the variable for the efficiency of resource consumption obtained 10%.

In summary, the results show that the proposed hypothesis was correct. What's more, it can be inferred from the different relationships between the variables that the most important variable is material, with a relevant weight of 33% compared with the others. Below, the results of the simulation data are presented (see table 4) which show the maximum, the mean, and the minimum obtained by the different variables. It also shows the correlation between the study variables in the behaviour of a building envelope when climate-compatible technology is applied (see Figure 1).

TABLE III. RESULTS OF THE ANALYSIS.

Results of the analysis of (A) climate compatible technologies

Factor	(B) Low-carbon technologies (Factor 1)	(C) Climate-resilient technologies (Factor 2)	(D) Clean technologies (Factor 3)	(E) Mitigation strategy (Factor 4)	(F) Technology strategy (Factor 5)	(G) Adaptation strategy (Factor 6)
Variable	Level of CO2 emissions	Heat insulation in a building envelope	Energy efficiency	Efficient consumption of resources	Material	External temperature control
Bad	70%	60%	40%	10%	30%	20%
Fine	0%	10%	20%	40%	30%	20%
Good	10%	30%	20%	40%	40%	30%
Very good	20%	0%	20%	10%	0%	30%
Total	100%	100%	100%	100%	100%	100%

Climate compatible technology

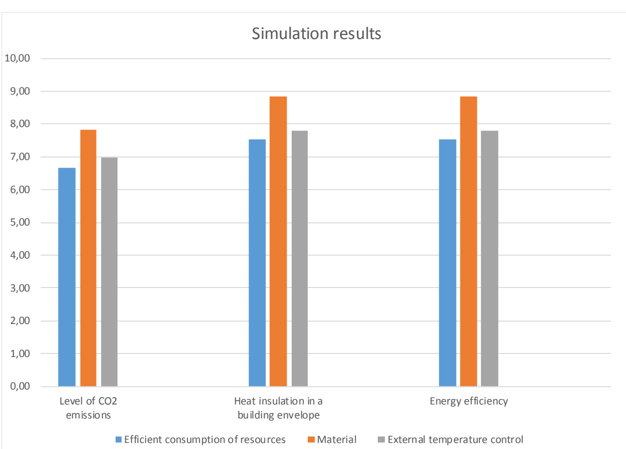
Factor	(B) Low-carbon technologies (Factor 1)	(C) Climate resilient technologies (Factor 2)	(D) Clean technologies (Factor 3)	(E) Mitigation strategy (Factor 4)	(F) Technology strategy (Factor 5)	(G) Adaptation strategy (Factor 6)	Total %
Variable	Level of CO2 emissions	Heat insulation in a building envelope	Energy efficiency	Efficient consumption of resources	Material	External temperature control	
Relative weight	8,3%	11,2%	11,2%	13,2%	33,2%	22,9%	100,0%

TABLE IV. RESULTS OF THE ANALYSIS.

Group 1 -Simulation

Factor	(B) Low-carbon technologies (Factor 1)	(C) Climate-resilient technologies (Factor 2)	(D) Clean technologies (Factor 3)	(E) Mitigation strategy (Factor 4)	(F) Technology strategy (Factorn 5)	(G) Adaptation strategy (Factorn 6)
Variable	Level of CO2 emissions	Heat insulation in a building envelope	Energy efficiency	Efficient consumption of resources	Material	External temperature control
Simulation 1	3,9	2,5	1,0	3,3	4,1	2,1
Simulation 2	4,0	3,0	1,9	3,5	3,0	4,1
Simulation 3	1,4	4,7	1,2	3,5	2,1	3,3
Simulation 4	1,3	2,1	2,6	2,0	4,9	2,9
Simulation 5	1,5	4,7	3,1	2,3	1,8	3,5
Simulation 6	1,6	1,9	4,3	2,9	4,1	1,3
Simulation 7	1,3	1,4	3,1	1,0	4,5	3,3
Simulation 8	4,1	1,0	1,0	2,6	3,9	4,0
Simulation 9	1,8	4,0	2,6	4,9	3,8	4,5
Simulation 10	1,8	1,0	5,0	3,2	2,2	1,0
Mean	**2,3**	**2,6**	**2,6**	**2,9**	**3,4**	**3,0**
Median	1,7	2,3	2,6	3,1	3,9	3,3
Mode	1,3	4,7	1,0	3,5	4,1	3,3
Variance	1,5	2,0	1,9	1,1	1,2	1,4

Fig. 1. Result of data simulation.



IV. DISCUSSION

As was previously mentioned, the aim of this work was to describe the concept of technology which is compatible with climate change and the capacity for resilience of such technologies when applied to the building envelopes in urban areas. As a result, this study identified that the combination of the six study variables can be used to create these climate-compatible technologies.

The use of simulation tools validated the proposed hypothesis and proved that the proposed model can be applied practically in the real world. It's worth pointing out that this is just a first experiment on the topic of climate-compatible technologies, which can be explored on a deeper level. It's thought that more detailed future exercises may lead to the development of certain components of the building envelope and the application of Phase Change Materials would allow for the resilience capacity of a building to be increased.

As was established in the results, the resilience capacity of a building is not homogenous with the external temperature. For this reason, it must be emphasised that this type of response is integral and requires a deeper study of the interrelationships than has been put forward here. It is necessary to identify these correlations through experimenting with a variety of Phase Change Materials applied to building envelopes. Therefore, it is of the upmost importance to carry out a technological study of the different technologies directed towards the climate. It would then be possible to identify which will be the most appropriate technologies for tropical regions and to manage the appropriate ones for this type of region. That's why techniques such as simulation are extremely useful given that it allows for resources which are often limited in developing countries to be saved.

V. CONCLUSIONS

In summary, it is necessary to introduce the concept of climate-compatible technology because it will be extremely useful when it comes to developing sustainable and resilient design processes. This means having a multivariable vision of the process of sustainable design in addition to emphasising the innovation and industrialisation processes with the aim of reducing the impact produced by climate change today.

However, this concept requires an interdisciplinary approach so that the actors that intervene in the construction sector can understand and incorporate these concepts in their daily work. Therefore, an interdisciplinary research group composed of architects, physicists and mathematicians is convenient. Currently the research team is made up of an architect and a physicist. In conclusion, this first experiment allows for the development of a conceptual framework for the application of the variables identified.

In the future, it is hoped that this strategy will be strengthened and incorporated into the actual processes of architectural design. So, research team want to improve the model using a robust statistical tool and then they will write a code that allows to development a software.

On other hand, research team want to design an indicator that give to designers a decision tool to implant clean technologies in the field of construction. So, designers could give an input variables to model and then the model could give them an answers that shows the optimal technologies to counteract the effects of climate change.

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