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REVIEW

The Impact of Using Nano Self-Healing Concrete in Flexible Houses

Hoda Ramezani* and Pervin Abohorlu Doğramaci†

In recent decades, modernist ideology almost lodging questions the designs of life and, approaches the building as something that can alter over time and, not harm the environment. On the other hand, a wide range of advanced materials has affected the prospects of science and technology in construction. In the same way, self-healing materials lead to the advancement of economical innovation within the field of nanotechnology.

Although it has been claimed that self-healing materials a sort of Nano materials to form multidimensional values for sustainability and green buildings, the results of value creation are still insufficiently understood and taken into account in decision making.

For this reason, the purpose of this project is to examine the structure of self-healing materials and their impact on the design process of green buildings. This paper provides a comprehensive assessment of nanomaterial-based self-healing concrete using grounded theory, a type of qualitative study that includes environmental impacts, sustainability, and methods of use and its placement in the design of flexible houses by a type of quantitative method, a Causal-Comparative. It will be discussed and sought to determine what the future of Nano-materials and their implications for flexible architecture will be.

Keywords: Sustainable Technology; Nano Technology; Nano Materials; Flexible Houses; Self-Healing Materials

1. Introduction

In the science of concrete manipulation of new cement technologies in the scale of Nano to create new properties and generation of concrete with a new suitable structure (Aljenbaz & Çağnan, 2020). Although there are many different decent kinds of technologies that are innovated in the field of concrete, self-healing concrete has taken the lead in the last two decades (Wang et al, 2020).

The reason that these materials are grabbing the attention itself is their ability to increase the concrete's life and decreasing the cost and need of controlling the long building constructions (Idumah & Odera, 2020). The relation between the architecture and Nano innovations is through the Nano technologies by introducing new kinds of materials, which in this regard the clear examples can prove this claim, such as self-clean glasses, self-mending solid, light-emanating surfaces, adaptable photovoltaic boards, and anti-bacterial coverings (Aljenbaz & Çağnan 2020).

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The new kind of architecture by paying attention to the new type of lifestyle in the process of improvement brings the houses to the adaptability and flexibility and also a new interpretation to and demand for the smarter design of the living aspects (Till & Schneider, 2005). Determination of the flexible houses for housing that can adapt itself to the needs of the users in different design layouts prior to the occupation and having the ability of housing a person and the needs during the times. It should also have the potential to adjust itself to the new technologies and even the demographical changes and in some cases adapt itself from the housing design to something else (Hatipoglu & Ismail, 2019). The flexible housing lets the users undertake the responsibilities in the post-occupation period and also during the design process. Also, the flexible houses after time relied on the user's plan procedures (Till, & Schneider, 2005).

The use of Nano-Self-Healing concrete in flexible houses would be associated with environmental costs. Careful analysis and selection of materials and how to combine them with modern architecture can dramatically improve comfort and efficiency, as well as greatly reduce the environmental impact of the life cycle. The problem that this article seeks to find is how to improve the current problems of Nano-self-Healing concrete to reduce costs and the effect of using this material in the construction of flexible houses, which is a concept of green architecture. In

short word, how to reduce the challenges of using Nano-self-healing concrete at the general level of construction with green architecture aspect.

For this purpose, in the beginning, will try by description method which is the qualitative methodology to explain Nano-Self-Healing concrete and describe the characteristics, environmental impacts, sustainability, and methods of using it then, by grounded theory will attempt to defend the reduced challenge of using this material and flexible houses, and in the end by correlational research design measures a relationship between two variables (flexible houses and self-healing concrete), it will be discussed and sought to determine what would be the future of Nano-materials and their implications for a flexible architecture.

2. General Problem

Nanotechnology in concrete science involves the techniques of manipulating the structure on a nanometre scale to create a new and suitable generation of cement composites with ideal mechanical behaviours, and even concrete with new properties can be created. High nanoparticle costs prevent the increasing development of these products and their use in industry, so the exploitation of nanotechnology in the concrete industry on a commercial scale is still limited to few products available in the market. Finally, there are challenges that need to be addressed before the expansion of nanotechnology in the concrete industry, such as the uniform distribution of this kind of material, compatibility of nanomaterials with cement, processing, manufacturing, safety, transportation issues, mass production, and costs, in addition to introducing these new materials to the community through social infrastructure.

2.1. Research Problem

The use of Nano-Self-Healing concrete would be associated with environmental costs. Careful analysis and selection of materials and how to combine them with modern architecture can dramatically improve comfort and efficiency, as well as greatly reduce the environmental impact of the life cycle.

The problem that this article seeks to find is how to improve the current problems of Nano-self-Healing concrete to reduce costs and the effect of using this material in the construction of flexible houses, which is a concept of green architecture.

2.2. Research Question

In today's world, concrete is the most widely used material after water in the world. Using the unique properties of this material with existing nanomaterials such as nanosilica, it can be used effectively to make a new material with extraordinary capabilities. To be used once the question that arises is that, how to reduce the challenges of using Nano-self-healing concrete at the general level of construction with green architecture aspect.

2.3. Research Methodology

In the beginning will try by description method which is the qualitative methodology to explain Nano-Self-Healing concrete and describe the characteristics, environmental impacts, sustainability, and methods of using it then, the grounded theory will attempt to defend the reduced challenge of using this material and in the end, by causal-comparative, it will be discussed and sought to determine what would be the future of Nano-materials and their implications for a flexible architecture.

3. Sustainability and Nanotechnology

In today's world sustainability has become one of the most significant issues in almost every field, so that architecture is not an exception. One of the main goals of sustainability is to provide health improvement for humans and protecting the environment. With this information, Nanoscience reveals itself as a kind of sustainable technology that is providing and introducing different kinds of facilities and materials that positively affect architecture and construction (Mohamed, 2015).

In the construction field, lots of attention are turned to the Nano techs due to their special and positive behaviours which can reduce or even solve the existing problems, and also, they can change the way projects run and demand (Aljenbaz & Çağnan, 2020).

3.1. Nano Cement materials

Concrete has multiple features which are its parts, stage, and scale. the ingredients can be mentioned the water, many other added materials of minerals and different mixtures, and this ingredient can differ in scale, proportions and etc. according to the projects and situations (Zhang et al, 2020).

In the concrete by enrolling Nano blocks like particles and tubes the concrete face incredible behaviours and properties, and also by attaching molecules to the concrete particles or doing other things to the ingredients the interfacial interaction of the concrete ingredients can be promoted (Aljenbaz & Çağnan, 2020).

The Nano concrete is composed of different scales of the micro and Nano meter scale crystals which mix and attach by water and the mechanism of degrading in the ingredients from Nano to micro and macro in the way that the properties of each one come from smaller scale sized ones. The amorphous segment is the calcium, silicate, and hydrate which are Nano themselves and they have the responsibility of gluing the concrete together (Sanchez & Sobolev, 2010).

3.2. Nano Self-Healing Cement Materials

The self-healing concrete has taken the attention to itself between many different innovative technologies in the field of concrete. Because it has the potential to increase the life span of the concrete and decreasing the financial costs of the framework of the long building construction handlings (Idumah et al, 2020).

The most common innovative ingredients of the self-healing cement for the concrete are steel, polyethylene (PE), and polyvinyl alcohol (PVA) which are used for promoting the main goal of the concrete which in this regard is self-healing. the mechanisms of these fibbers can be mentioned as, improving the shape and appearance of the cracks, and most importantly improve the healing ability in the tensile strength of the concrete, for example

by using the steel cord and PE fibbers that makes the concrete to heal itself to the first tensile strength (Zhang et al, 2020).

Another favorable aspect of concrete mixes is their capacity to produce strength by a method called carbonation. The presence of carbon dioxide in water can react with the particles of anhydrite cement resulting in secondary hydration. Particles from portlandite (calcium hydroxide) react with carbon dioxide to create mineral precipitation based on calcium carbonate (Sangadji, 2017).

3.3. The Advantages and Disadvantages of Self-Healing concrete

The greatest benefit of self-healing concrete is its potential to last over decades or perhaps centuries, with an estimation of 200 years. thus, it can be argued that its sustainability can be improved by replacing such materials in historic buildings and these national values could be further preserved (Mishra et al, 2019).

Reduction in the amount of maintenance on the surface of the concrete is another advantage related to self-healing concrete. Filling and covering the cracks on a regular concrete surface is essential in order to prevent growth in cracks. This is something that must not be overlooked or thought about with self-healing concrete, opening up more time for other things (Muhammad et al, 2016).

one of the major disadvantages of self-healing concrete at the moment is the cost. Many people prefer concrete because it's the inexpensive construction material for their designs but, self-healing concrete is fairly recent and extremely rare. As such it can be costly. And it will be costlier and time-consuming to replace those new materials with older ones. The second disadvantage of self-healing concrete is that not many contractors are already aware of how to use this product. It is still new and not every company uses it as such, and not every contractor is instructed to do so. Seeking a contractor that uses this material and has expertise based on where you stay can be difficult (Mishra et al, 2019) (**Figure 1**).

4. Participation of Self-Healing Concrete and Flexible Houses

People always modify the layout of their houses to retort to many unavoidable factors like self-identification, lifestyle, technological advancement, and family structure. They demand long-term solutions so they'll change their building layouts when needed with minimum investment (Ahmed, 2011).

Consequently, flexibility in housing to adopt for the variation is an almost evident necessity. Flexibility is perceived as the therapy for rigidity of the building and helps to lengthen the building's lifespan as well as to optimize resources and energy (embodied) (Dhar et al, 2013). The idea of flexibility in buildings in Europe began in the early twentieth century after World War II due to the extreme housing crisis (Ahmed, 2011) After years of research and

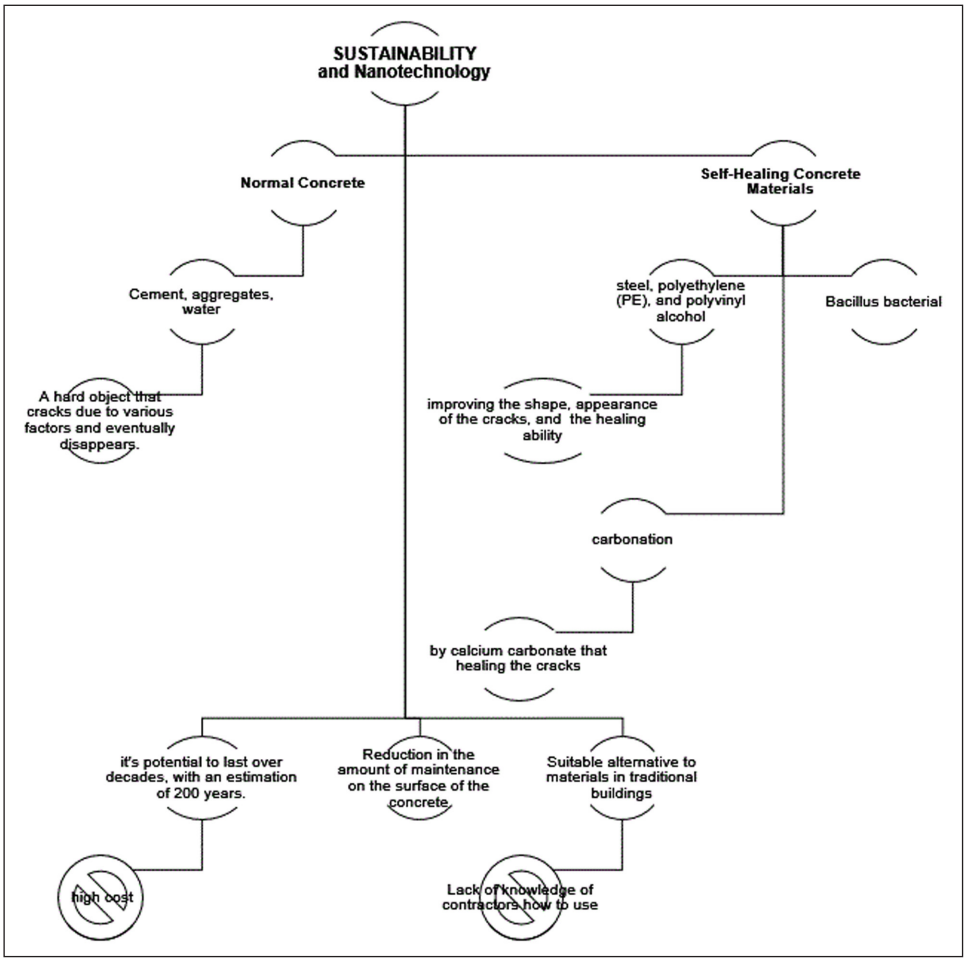

Figure 1: Summary of Sustainability and Nano Self-healing Concrete.

development of this idea, some researchers today argue that building materials and designs are highly influenced by flexibility. life cycle deployment by renovation and re-use of existing stock is generally more sustainable, more effective, and more efficient as a replacement by new construction. Also, the systematic management for adaptive re-use of the existing building may save a basic value of resources and time. Thus, design for flexibility can save the financial and natural resources of a developing country (Dhar et al, 2013).

The size and shape of the buildings mostly provide the function of the construction and its life span, in this regard mostly the small size constructions are used for the residential functions and are placed in the outer parts of the cities and in the suburb, and also like most of the buildings the concrete is one of the main construction materials, Due to the size of the residential buildings the main use of the concrete goes for the foundation, columns and slabs that by using the self-healing concrete if the function of the building is suitable and does not change can expand the life span of the construction (Abulmagd & Etman, 2018).

It is obvious that by increasing the life span of the constructions, architects should also change and improve their design strategies and standards. In this regard the main aspects that architects should consider in their design process are the future technological improves and demands in the buildings, also the necessary changes and the lifestyle of the users. Also, the suburb changes and improvements in the future that the building should still function pretty well in the new context so that the design should be flexible enough to accommodate the upcoming changes (Alhalabi & Dopudja, 2017).

4.1. The challenges of using self-healing concrete in flexible houses

Flexible housing can be specified as housing that is designed for choice at the design stage, both in terms of social use and construction, or designed for variation over its lifetime (Alhalabi & Dopudja, 2017). Flexible housing as residential buildings is still counting on reinforced cement concrete (RCC) frame and brick walls. Usually, load-bearing brick walls or short span RCC structure promotes economic efficiency within the construction (Till & Schneider, 2005). In this way, self-healing concrete (SHC) is far simpler than normal concrete can use as a sustainable and suitable material in houses (Muhammad et al, 2016).

Unfortunately, cracks might happen in the concrete at any stage of construction, due to many different reasons such as heat pressure, excessive load, sudden loss of water, chemical reactions, the uneven spread of ingredients in the concrete mixture and etc. (Ansari et al, 2020). Also, it should be mentioned that the cracks would definitely decrease the immunity and load-bearing strength of the structure so that the safety of the concrete plays an important role (Wang et al, 2020).

In the construction field, the Nano materials are providing great features toward the sustainability of the concrete like, energy preservation, high resistance toward corrosion, self-healing, environmental preservation and etc. (Wang et al, 2020).

Permeability and abrasion Concrete are containing Nano-particles which shows the ability of abrasion resistance much more than that of polypropylene fibber concrete (Abulmagd & Etman, 2018).

In general, during cement clinker's de-carbonation of lime and calcination reactions the carbon dioxide gas is released from OPC concrete. But this gas would be emitted much less related to the self-healing concrete (Huseien et al, 2019).

Economically feasible for very expensive constructions that the materials would be used in the high volume every day (Mishra & Leung, 2019).

5. Investigating and Analyzing of Self-Healing Concrete and Flexible Houses

The process of flexible design is a double stage, which is the design level of the mixture and finding harmony for the materials, and the user's level in which the composition of materials should be adjusted and applied for different needs and demands of the users or different users of the place. Resources in the flexible design are referred to as the manufacturing tasks which are enabled by different groups of flexibility elements. The labor, supply system is used for structural resources but the control system is used for infrastructural resources (Sangadji, 2017).

In the meantime, the use of a large number of modern materials may make the space beautiful and comfortable for users, but materials with different densities over time have negative reactions and cause destruction, among which nanomaterials have been welcomed with great efficiency (Abulmagd & Etman, 2018).

In this way, Nano self-healing concrete despite many different obstacles that are intervening in its usage additional structure can support other architectural spaces (Muhammad et al, 2016). Although It is obvious that the self-healing concrete is much more effective than the normal one so that some of the strong relationships between this material and flexible design prose would be mentioned.

5.1. Support

In flexibility design, the support is the physical setting which provides space and the possibility of making the buildings with the list limitation and a little work. There are local factors that highly control the support, such as the regional weather, regulation of buildings, architectural design, materials and etc. although the façade is important and considered as one of the main elements of the support, the strong issues are toward the environment, a dimension of opening and its characteristics, local material, and technology, even the architecture (Dhar et al, 2013).

Also, lots of layouts for every house should be considered in support. Every residential unit should be able to change the floor area whether by changing the boundaries within the support or adding another construction.

Also, it cannot be underestimated that the support or even part of it should adopt non-residential functions. In this regard, there are obstacles that make the design difficult and sometimes out of control (Dhar et al, 2013). For example, the corrosion of the materials, crushing materials during work or cracking materials during execution especially the structure. Fortunately, nowadays lots of technological materials are helping to eliminate many of the obstacles or at least make the problems less annoying, like using the self-healing concrete the structure can be supported. It is one of the most efficient materials that is endowed with any environmental conditions, and removing cracks in concrete materials in the field of support, both in the structure and in the facade of the building can extend the life of the building (Abulmagd & Etman, 2018).

In the healing proses by having the water passed through the cracks of the concrete, the calcium that exists in it would be transferred to the cracks as an insoluble form, so that not only it heals the cracks and increase the mechanical function of the concrete without any external help, but also it makes it water-impermeable and has an effect on a long life of material and structure (Sangadji, 2017).

5.2. Toward a variety of layouts

In the residential units, there are three spaces that can determine the layout from the adaptation point of view. The first one can be the special purpose space which is designed for a special function and it might be used during special times so that analysing the function would determine the size and dimensions of the space.

The next space is the general one in the residential unit which is mostly a large space that can be arranged in different ways to accommodate many functions and activities such as sitting, eating, ordinary activities and etc.

finally, the service spaces where is used for a short period of time and specific activities, such as restrooms and stores, Also, it should be mentioned that the kitchen in this study is categorized as service space, not the general space (Dhar et al, 2013).

Modern architecture uses a variety of materials to make design spaces more efficient but unfortunately, in all the spaces that concrete is used, cracks are observed, and the result would be a decrease in the durability and strength, and also of repair costs would be applied. On the other hand, there is a belief that the concrete Is unbreakable, but it is not strong toward the tensions so that the cracks can decrease its strength. But by using self-healing concrete in any space and environment these problems are solved, which I this regard there are examples of self-healing concrete that would be mentioned (Zhang et al, 2020).

One of the examples is the Nano self-healing concrete with a polymeric, the hydrophobic nanoparticles with an extra layer of polymer, this concrete in contact with moisture start to form the healing material so that this concrete can be used in places like services such as bathroom and kitchen (Abulmagd & Etman, 2018). Also, the mineral formation by the help of the bacteria's in the nature for the concrete (bio mineralization), that for this kind of self-healing concrete the uncontrolled microbial metabolic activity in nature which should be mention this process occurs in an anaerobic environment or at the toxic-anoxic area, can help the healing of concrete. Also, this method works best in the presence of carbon dioxide. It happens through the change of carbon dioxide to carbonate. It makes the calcium carbonate rain to helps the cracks to be sealed. so that the best place for using this concrete is the exterior places, such as the building facades, which is the best choice for the facade in this day's environment (Sangadji, 2017).

5.3. safety

A notable point in flexible designing and building is to maintain the security of the structure and maintain its longevity. The greatest damage to buildings is due to changes in environmental conditions such as landslides or earthquakes. The most important property of earthquake-safe constructions and structures is flexibility.

During the earthquake, the flexible structures face the least amount of damage in this process and that rigid and inflexible structures crumble and collapse. However, in both cases there is a possibility of damaging the building materials as a crack and demolition (Sangadji, 2017).

From the safety point of view, cracks in the concrete are can cause serious damages and danger, so that it should be regularly checked for further damage and cracks. So that in this regard the self-healing concrete can eliminate the control over the concrete for its caused cracks. But the main question is whether the healed cracks would gain their initial strength or not. The studies revealed that the gained strength in the sealed area in the self-healing concrete is about 25% of the original one, which is 15% of the ordinary repair on the concrete (Alhalabi & Dopudja, 2017).

5.4. Economy

Cost plays a major role in any construction project which means the aspects costs of repairing and taking care of, against demolishing and building from the beginning and of course the return of the profit even from the service or benefit or finance. It is noteworthy that the design of sustainable buildings and the use of new materials, although initially more expensive than other methods, will ultimately be more economical (Sangadji, 2017).

According to WBCSD (World Trade Association for Sustainable Development), the annual consumption of concrete in the world is about one ton per person, which by multiplying this number with the number of population on the planet (about 7.6 billion), it will achieve a significant volume (Espindola & Froese, 2020). Also, the cost of maintenance, repair of constructed structures will be exorbitant costs that usually determine the useful life or duration of operation of a structure (Sangadji, 2017).

In the beginning, the cost of the self-healing concrete, that initial cost is much higher than the normal concrete (Muhammad et al, 2016) (**Table 1**). To produce self-healing concrete, double costs are supplied to provide the following conditions:

_ The MBS culture medium used to produce spores
_ Activities required for assembly and maintenance of the work process
_ Supply of required energy
_ producing product (Sanchez & Sobolev, 2010).

According to these conditions, to produce a scale of 1 m^3 self-healing concrete can be calculated as follows:

_ The cost of work per hour is about 50 euros
_ In total, about 3 hours of daily work is required
_ The cost of electricity is 0.09 per day (Silva et al, 2015).

Table 1: The costs in Euro to produce 1 kg of Bacillus sphaericus and non-axenic production of an ureolytic bacterial (Silva et al, 2015).

	Axenic pure culture production	Non-axenic mixed culture production	Factor
Spores cost per kg	435	145	30
Self-healing agent cost per kg	480	595	8
Cost per activity unit (i.e. g urea hydrolysed per g CDW per h)	350	48	30

The method must be optimized to get practical spores that keep up ureolytic action over a long capacity time to perform the hydrolysis of the urea and incite a massive calcium carbonate precipitation. It is additionally fundamental to discover a cheap epitome handle, giving the essential security to the spores, keeping up or somewhat changing the concrete proprieties. Summarizing, from the temperate point of see, for a bio-based item for self-healing and/or self-repairing in concrete structures, costs of almost €15 to €20 per m^3 of connected concrete are justified (Silva et al, 2015).

6. Desccution and Result of Self-Healing Concrete and Flexible Houses

According to studies performed in this study and comparing the impact of using self-healing concrete on flexible houses that both of them try to more durability and be more sustainable, it can be argued that while the use of self-healing concrete has not yet been promoted and has many challenges, on the other hand, flexible houses, while trying to be controlled by the user, still cannot be completely flexible due to some construction factors or service spaces, but it has a great impact on the users' living in the building. they have many benefits, including a reduction in the cost of repairing and fixing materials, extending the life of structures, and reducing the preservation issues.

Based on the use of self-healing concrete with an efficiency of 25% of the crack and damage repair of the original strength, the need to repair or replace materials would not be required, therefore increasing the building's durability.

Thus, with 80% response to the needs of residents in contemporary buildings, self-healing concrete with the ability to repair cracks will increase this durability by 25%, according to the researches. In this way, in addition to supporting all spaces and structures of the building, these materials will provide a safe environment for users to live in. Although all efforts in the construction process meet 100% of the needs of all layers, the presence of self-healing concrete will double these efforts and improve the durability of the building (**Figure 2**).

7. Conclusion

Given that the allocation of resources and the use of important criteria for building design, especially in developing countries, and today the ideology of modernism has changed the design of life and brought it closer to the building technology and industry, architects have resorted

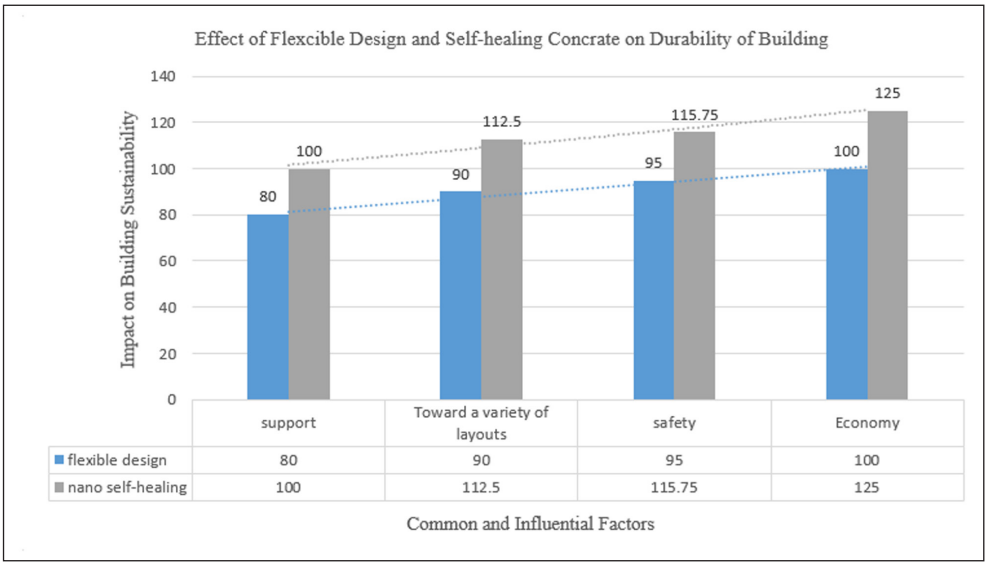

Figure 2: Investigating the Effect of Variables on Building Stability (Created by the author, 2020).

An important notable point is in both variables (flexible design and self-healing concrete) the initial cost is very high, and since the economic part of any project is a turning point, it is illogical at first glance to accept this cost. However, due to the costs during the use of the building, such as maintenance, possible changes spaces according to change users need, or repair materials, it can be claimed that these two variables will be very economical and cost-effective.

to flexible design to respond to this new perspective and the changes needed. For example, houses, responsive to all users, and their needs, in the long run. This type of design provides new dimensions in building design (especially support) to offer potential opportunities to change the layout of the demand axis with minimal cost.

But this would not be possible without the link between architecture, technology, and materials. these days, the potential of nanotechnology to improve the performance of building materials, especially concrete, which has the highest consumption, is significant, which leads to the development of concrete composites based on the improvement of mechanical properties of concrete. Self-healing concrete is one of the most amazing Nanoproducts in concrete, which is characterized by many important features such as less pollution, reasonable price, environmentally friendly, and high-durability performance in harsh environments.

Therefore, the integration of flexible design and self-healing concrete materials can have a significant impact on human life in such a way that by implementing high-strength and durable cement composites, the need to use the environment to build materials, repair or replace it is reduced. This means decreasing the use of energy and manpower during construction, which stops polluting the environment. On the other hand, due to the high mechanical strength of these materials, buildings will have a longer life and this factor on the sensitivity of architects to more principled design and more precisely architectural spaces based on different needs of humans.

Competing Interests

The authors have no competing interests to declare.

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