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Effect of Self-Healing Concrete on Building Durability in the UK Construction Market

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Abstract: This study explores the effect of self-healing concrete in existing buildings and its crucial impact in terms of sustainability, permanence, and access to the internal strength of concrete in order to contribute to the process of protecting the internal parts of the building from the reinforcing steel structure as well as prevent the internal corrosion of iron reinforcement. This study also highlights the market growth side of the cement sector for self-healing products and access to growth in markets from (24 to 26%). Self-healing concrete technology is an advanced technology with self-healing compound. It allows for the repair of small cracks that affect the structure, which contributes to the support of the building to repair and rehabilitate the building. It also helps in repairing internal cracks without any financial costs. Compound prepares to spread when cracks occur and when reaching an appropriate environment in order to work to rehabilitate cracks. In the coming years, as growth thrives in order to reach the purchasing power in a prosperity in the cement sector, which improves internal and external investment and increases in attracting investors in the cement sector. The study aims to reach scientific research of high quality and it specializes in studying the United Kingdom market and the prosperity of self-healing concrete in the cement sector. Moreover, it contributes to the prosperity of self-healing products because of their contribution in reducing the financial costs that are under the building maintenance and rehabilitation department. This study also contributes to studies in the United Kingdom, which resulted from the impact of the cement market that will probably flourish and grow in the coming years. The researcher suggests that the development of the self-healing concrete will be reflected in the cement sector, which will be a reason for improving and developing self-healing concrete that will spread in sectors other than the cement industry.

Keywords: Construction market perspective, Durability, Permanence of the building, Self-healing concrete.

1 Introduction

Concrete is the major material that is used in the construction field from the beginning of building until the construction of bridges and walls. Concrete is made from raw materials of cement, mortar, and water and is placed in proportional quantities for the concrete mixture. Therefore, concrete is considered the primary axis in construction operations because it contributes to preserving the reinforcing iron from external environmental factors that can cause damage to the iron parts. Concrete works on its packaging and despite the external conditions faced by it, which might cause the cracking and weakening of the concrete, whether by natural or external influences [1, 2]. In terms of technological developments in concrete regarding solidity and sustainability, self-healing concrete is considered to be one of the most important developments in concrete technology, which was presented for the first time in the year (2015) by the Dutch inventor (Jonkers) who contributed to the discovery of this development. This achievement is considered one of the most important discoveries in biology and was initially called "living concrete", since it includes bacteria in its components that can live for a period of 200 years inside the concrete. This smart material has interesting potential applications in infrastructure civilization. For instance, this development contributes to the increase in strength and hardness of concrete as well as the durability that contributes to improving the shelf life of concrete. This development contributed to solving many problems in the cement sector since this technology began to increase production more in the cement sector and this helped in tightening the economic gap that passes in the cement industry. This approach to solving problems contributed to the production and innovation of technological development towards economic growth in the cement sector; the emergence of self-healing concrete in the construction sector and the engineering contracting sector which indicates an important improvement in the market and its impact on the construction market. It also represents an opportunity to invest in new development projects that we can benefit from. [3, 4, 5].

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Self-healing concrete is also called smart concrete or live concrete. This material is made up of natural concrete components; cement, mortar, and water, as well as the main component, which is bacteria; a type of natural bacterium that can live in cement for long periods of time. Food is also mixed with bacteria from calcium lactate during mixing where the preparation of bacteria is carried out in incubators stimulating them to environmental conditions before mixing. As soon as the bacteria is mixed in concrete, it can become a liquid table that is sprayed on the cracks of existing buildings that did not have the element of bacteria. The first experiments were held in an advanced concrete project in the cement sector by a group of researchers from the University of Bath and the University of Cambridge to work on self-healing materials, in "2015". The United Kingdom began to research and studies to develop the product so that it can be applied to existing buildings that were built to protect from corrosion and for non-existing buildings to work on Increasing the quality of concrete and protection is an external factor and erosion, which also contributes to increasing the durability and strength of concrete. [3, 6].

The United Kingdom's construction and building market annually spends approximately "£ 40 billion" on maintenance and rehabilitation sector of buildings and facilities, which is high in cost in the United Kingdom market. Therefore, self-healing concrete is considered a very good investment in concrete technology that contributes to saving costs and reducing them from maintenance and restoration as well as increasing the quality of concrete and the durability of it. The United Kingdom market helps in the growth of concrete technology in the cement sector, which helps in the market growth of the cement industry and the strengthening the construction market in the United Kingdom. [3, 7, 8].

This study looks into the effect of self-healing concrete on the construction as well as its impact on existing and non-existing buildings in terms of strength and sustainability. It is based in the United Kingdom and its impact on the growth of self-healing concrete. The researcher will study the United Kingdom market and the role that self-healing concrete is playing in it. In addition to its great impact on buildings. This will be highlighted through the analysis of recent studies and researches on the topic. The methodology used in this dissertation is the use of an interpretative and research approach and narrative analysis, which is applied to the qualitative method of secondary data.

1.1.Research Question

The research is the answer to a question in which the factors and objectives that will be reached are identified and explained in detail in the literature review and research analysis section, and that the research question: What is the effect of self-healing concrete technology performance on existing and non-existing buildings in the UK from the construction market Perspective and influence on the durability and permanence of the building?

1.2. Research Objectives & Aims

Objectives to be achieved in the research:

- Improving purchasing power, increasing productivity for the construction market, and contributing to the introduction of new technology to the market, from appropriate costs and better quality.
- To evaluate the effect of self-healing concrete on existing and non-existing buildings through the strength and durability of concrete in the structural frame of the building.
- Repairing the concrete cracks of the existing buildings, increasing the effectiveness of the self-healing materials, and reducing the damages that contribute to reducing the built life and efficiency.
- Building strong relationships with investors in neighbouring countries, investing in concrete technological development, which is one of kind unconventional concrete (bio-concrete) that is greatly affected the cement industry.

The objectives focus on several matters, and as the first aspect of the objective is to improve the purchasing power of the contracting, engineering, and construction sector as well as to contribute to the development of the concrete industry and the entry of new concrete technology in the cement industry sector. Moreover, work on reducing costs through maintenance and rehabilitation of buildings and facilities where concrete contributes self-healing materials to reduce costs by mixing it with concrete. The second and the third objective focus on repairing concrete cracks and reducing damage to non-existing buildings as well as the maintenance of existing buildings and increasing durability and strength by adding and improving concrete with self-healing materials. The final objective is to contribute to strengthening relations between other sectors and improving the production of the cement sector and attracting investors to the cement industry sector through implementing new technology that works to self-heal and reduce costs in order to increase strength and durability. Additionally, these materials contribute to preserving the environment are eco-friendly, which is a major positive feature that will contribute to the power of purchase and

investment.

This study aims to contribute to the development and improvement of the cement sector through self-healing concrete, which has a great impact on the construction market and the contracting sector. In addition, it helps in the growth of self-healing material that contributes positively to stimulating the United Kingdom market in the cement sector. Self-healing concrete increases the strength and durability of concrete where the buildings are considered non-existent a concrete mixture with self-healing elements and components is prepared. In case of the existing buildings, they are treated by injecting or spraying the self-healing materials which helps in improving and increasing the strength of the building's structural frame. The study includes the effect of self-healing concrete on concrete buildings and the behaviour of existing buildings that do not exist in terms of hardness and durability in the United Kingdom. It also sheds light on its impact on treating building cracks and studying the impact in terms of the construction and construction market and increasing the purchasing power and investment of the cement sector. [8, 9].

2 Research Methodology

2.1. Research Methodology

This research contributes to presenting the self-healing concrete which is considered a milestone in the cement sector. It also sheds light on the marketing side of this scientific achievement that contributes to the growth of the concrete market since it reached savings in market costs, increased purchasing power and attracting investors, which have the advantage of improving the properties of concrete. In addition, it studies its positive effects on the environment within the existing buildings as well as its contribution in repairing and maintenance of cracks. This study looks back on previous research held by former researchers and the differences that they faced through the research techniques that were used that contribute to helping them display their experiences and topics of scientific discussions and scientific research and scientific studies presented by researchers that contributed to the growth of self-healing concrete and growth in the cement sector in general. Consequently, the vast improvement in the market of self-healing compounds that contributed to linking and producing great information about the research being studied and its impact on the cement sector. The cement sector is in continuous development, which contributes to the development of the economy of the cement industry sector in the construction market. This study also includes an interpretation of former researchers' studies on developing self-healing properties and the work of a linking department for researchers to reach sources that meet the benefits, prosperity, and growth of the technology cement sector. [10, 11, 12, 13, 14].

2.2. Research Strategy and Design

The research methodology in this study employs studies conducted on self- healing concrete as well as technological developments in the cement sector in general. It also aims at linking research goals and sequences in the presentation of research topics that are discussed in detail in the research analysis and access to positive research and analysis related to the self-healing compounds as the self-healing technology contributes to the development of cement products and the improvement of their capacity. In addition, it plays a very positive role in the purchasing power and investment in the cement sector as the literary reviews of research show. The approach in this research is an interpretative and deductive approach to previous literature, highlights the development of research, and presents the latest developments in the cement technology and the cement industry market sector. This research aims at systematically studying all the challenges facing the cement industry sector as well as the systematic reviews that are included in the studies on the subject in a number of databases and sources. [14, 15, 16, 17].

2.3. Research Protocol of Data

Studies and researches that have been obtained from different databases will be analysed in detail in this research. These studies revolve around the topic of self-healing concrete in the cement industry and its role in the development of the concrete market as well as its impact on the market and the sustainability and permanence of concrete in the existing and non-existing buildings. Many research results were reached in initial stages but when defining the objectives, topics, keywords and the time period of the research, it contributed to improving and developing the method of research in order to be accurate. The results of the research are in an appropriate manner for the research and its goals, and where the time period was from (2004) to (2022) and the choice of keywords (self-healing concrete), (United Kingdom), (construction market perspective), (durability), (permanence of the building) helped to find the search results in the databases accurately, which contributed to the promotion of scientific research journals and literary books.

2.4. Framework of Research Methodology

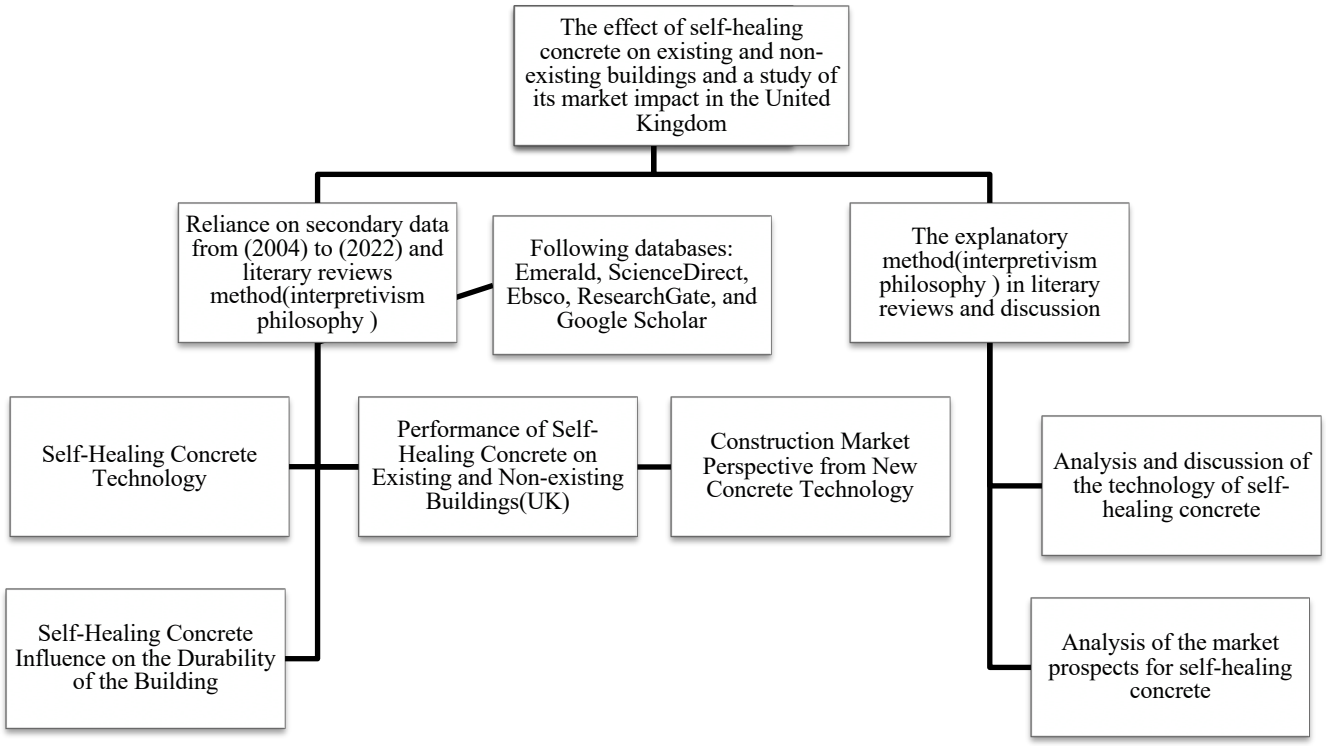

Fig. 1: Flow Chart of Research Methodology

3 Literature Review

Self-healing concrete represents the development that coincides with the era of concrete technology that began to appear as maintenance costs increased and external influencing factors appeared on concrete. Some of these effects have led to damage parts of the concrete, which caused damage to the basic elements of the building. This technology has contributed to the incorporation of bacteriology which uses components of bacteria that are synthesized, which is an essential element of the food of the bacteria that should be compatible with the initial concrete elements in order for the healing process to happen. Whether for existing or non-existing buildings, using self-healing processes contribute to supporting and reducing maintenance costs that are performed on concrete, which helps to improve the market and support the construction cement sector through export strength and purchasing power. Consequently, contributing to connecting investors in the cement industry, which has expanded to improve the economy in terms of investment in one of the important sectors in the industry.

3.1. Self-Healing Concrete Technology

The world of concrete is affected by various factors and influences that affect its properties. The new technology in the world of concrete consists of vital systems that are part of natural biological systems and that have the ability to self-heal. In other words, it is a self-healing concrete product that may enhance cement materials its ability and improvement in repair and deter influences and interventions external affecting concrete as well as providing an environment for a strong, sustainable and higher infrastructure. In the United Kingdom, self-healing concrete technology was tested; these tests were focused on the expansion and spread of cracks which activated self-healing. The concrete contains bacterial microcapsules the compounds bacterial data that are planted and mixed with cement containing compound healing self and are activated when the occurrence of cracks and material self-healing concrete. Consequently, improve and develop the cement industry and the development of concrete technology, which helped in the development of the gap in the

concrete market. [5, 18, 19].

3.1.1 Self-Healing in Cement Materials

Concrete is one of the materials that are used in construction and is characterized by strength at pressure, but relatively weak at tension points. Cement represents most of the composition in concrete. The formation of cracks in reinforced concrete is a characteristic of concrete, but when cracks are considered, wide this reduces the ability of concrete to protect the rebar corrosion is considered the main cause of a failure in the concrete structures. Micro cracks that are in the form of a matrix of cracks affect concrete, so the liquid materials become permeable, which reduces the strength of concrete. Studies and continuous development in the technology sector is improving and the emergence of self-healing of concrete elements is considered one of the most crucial ones. It works on increasing the efficiency and durability of concrete and the work of a layer of reinforcing iron from corrosion. [20, 21, 22].

3.1.2 Bio Cementation

Recent developments in the field indicate the development of a technique for the treatment of fissures in the field of building materials science. The self-healing of cement materials and the raising of strength and efficiency to enter biological development as well as the entry of a strong association of bacteria and limestone is a way to nourish the bacteria because it contains calcium lactate. Moreover, the bacteria aim to avoid problems that is related to the chemical reaction that occurs at the beginning of the cement mixture where the self-healing concrete is formed from limestone powder, which is a food for bacteria, calcium lactate, bacteria (bacillus subtilis), and cement elements are mixed with the cement components and where the reaction process begins. Accordingly, when cracks appear, the moisture factor and carbon dioxide are available in order for it to work as an environment to activate bacteria and close the cracks. This helps to form a strong layer that protects concrete from external factors and helps in self-restoration. [23, 24].

3.1.3 Using Bacteria in Self-Healing Concrete

The effect of water and chemical leakage on the concrete surface causes the creation of cracks, which leads to corrosion of the reinforcing steel and to the weakening of the concrete. As the manual repair of concrete structures is costly, the best option is to use self-healing concrete, which helps to reduce maintenance and increase the strength and bonding of cement materials. Its use inside concrete is like sleeping bacterial cells and viable cells which resist all pressures from physical, chemical and mechanical factors. It is added to a certain percentage of mixing during mixing and with food bacteria. Before mixing, it is placed in an incubator to suit the environmental conditions of the concrete and activated when appropriate conditions occur and begins the self-healing process after twenty-four days, depending on the depth and length of the incision. Self-concrete entry will reform the world of technology materials and construction as a form helped biotechnology to improve the world of concrete industry from all sides. [5, 11, 19].

3.1.4 Concrete and Corrosion

Corrosion that occurs in the rebar, greatly affects the deterioration of the concrete of the facility. The greater the amount of permeability of fluids and cracks, the greater the amount of corrosion and moisture, which influences the reinforcing iron. Moreover, the corrosion resulting from chloride is the most known problem faced by the construction and construction sector. Self-healing concrete helps in closing cracks and reducing the permeability inside the concrete, which helps to build a protective layer for the reinforcing steel and prevents it from eroding. [25].

3.1.5 Repair Cracks

Longing reforms are carried out when assessing the concrete structure in which cracks have become apparent as well as assessing its ability to withstand durability. The evaluation is carried out by a specialist with experience and engineering competence. Therefore, verification of the concrete structure and maintenance is carried out after studying the causes of the cracking, its width, the condition of cracking, the moisture of cracking, whether cracking is active or not active and, finally, studying the environmental conditions surrounding the cracking before starting to work with maintenance. After the evaluation and studying the cracking, the method used to maintain cracks is studied where the method of repair includes several things, including materials that fill the crack, the location, the surrounding environment, the behaviour of cracking, and the loading capacity. All this information is used for the maintenance chapped process, which is the proper way to know which of the two parties are cracking and weather the crack is active or inactive. The active crack is susceptible to movement and is maintenance directly. [26].

3.1.6 Repairing Cracks Using Biology

Self-healing process is about reforming the cement spot through self-healing concrete that contains a vital structure, which is applied to the biological self-treatment when the environment and conditions are appropriate to start the process of closing cracks. When cracks occur, the concrete weakens in terms of strength and durability and solutions

began to provide products that improve concrete during the occurrence of cracks. Those solutions include repairing the cracks manually, which is considered an expensive procedure, not to mention that it offers a short period of time for a permanent durability. This is why the discovery of a type of bacteria that is capable of closing cracks in an appropriate time period, which also works to protect concrete and prevent external environmental factors in order to close cracks is considered a huge improvement in the construction field. The process is carried out in stages in self-healing concrete that starts with the process of forming crystals resulting from food that was mixed in concrete through the secretion of bacteria to the limestone and this works on creating a dynamic layer of the product from the activation of bacteria bacillus subtilis through the appropriate environmental conditions to form a layer of limestone inside the cracking, which results in creating a solid layer and high permanence. [5, 11, 19, 27].

3.2 Performance of Self-Healing Concrete on existing&non-existing buildings (UK)

Self-healing concrete has a great impact on existing buildings in terms of increasing the strength and durability of concrete for the existing building where cracks are sprayed and injected with self-healing bonding materials. This helps to prevent obstacles and external influences from penetration into the concrete and affected the reinforcing iron in the construction structure in the United Kingdom started in 2015 [20]. In a study on existing buildings through realistic experiences on a reinforcing wall that has been exposed to cracks, the results that appeared confirm that the quality and strength of concrete that helped in giving the wall high durability. As for non-existing buildings, concrete components are mixed with the mixture. The intention is to add bacteria to concrete so the components become vital and give qualities to concrete from increasing strength and permanence to the entire established facility. The effect of concrete in existing and non-existing buildings is reflected in the building after a period of time. This is how the development of self-healing concrete has become a catalytic and reinforcing side of the world of cement and ready-mix concrete. [20, 28, 29].

3.2.1 Behavior of Self-Healing Concrete on UK Buildings

Cracks are one of the problems facing buildings in the United Kingdom. Accordingly, non-existing are mixed with the vital compounds of bacteria to become concrete self-healing, so the disposal of components inside the concrete becomes supportive of the building, which gives the durability of the concrete and strengthens the building. This strength increases in the passage of a period of time and the appearance of cracks. This process of repairing and self-healing of cracks begins, which helps to protect the rebar from corrosion. As for the existing buildings that are not mixed with self-healing concrete components on which cracks appeared, there are many used methods, including injecting voids with cement material with one of the self-healing compounds, or by spraying the liquid with properties of self-healing on cracks to become an insulating material that works to protect the reinforcing steel and close the cracks, so the self-healing concrete will be disposed and formed inside the buildings. [20, 30, 31].

3.2.2 Sustainability and Development of Self-Healing Concrete

Self-healing concrete helps to build and improve concrete production and its development is continuous in the world of concrete, which begins from the period of incubation of bacteria and the internal development of concrete components for self-healing to the addition of nanomaterial working in order to improve and accelerate the self-healing process where it can remain for a period of life inside the concrete in buildings. The list has a longer period and helps in the process of permanence and improving its internal properties, sustainability. Concrete permanence is produced through the development of the internal components of self-healing concrete where the bacteria is activated by calcium lactate and nanomaterial that improve the conditions surrounding bacteria which help speed up the healing processes and self-work protection layer of steel reinforcement from corrosion. [32, 33].

3.2.3 The Impact of Self-Healing Concrete on Buildings Maintenance

Self-healing concrete has the ability of self-healing, which works to improve the characteristics and properties of the building, and that has a strong impact on the maintenance of buildings. One of its effects is the durability and strength of the materials granted by the vital materials to the concrete to improve and close the cracks, as well as to increase the durability of the section that was done the process of self-healing. The impact in terms of characteristic Self-healing does not require workers, so the construction process will be self-cracking, and this gives us plenty of reasons for using self-healing concrete, one of them is to facilitate the process of maintenance of buildings that need to be largely restored. Another important one of the features that plays a big role in the restoration process is the sustainability of sealing cracks and the permanence of buildings that the self-healing concrete provides. [28, 34].

3.2.4 Performance Treatment by Self-Healing Concrete

Bacterial performance is characterized by its speed of self-healing through the vital components of bacteria that are incorporated into the concrete, which are under an appropriate environment to start the process of self-healing. The

environment before mixing inside the concrete is prepared under environmental conditions suitable for incubation inside the concrete and lives twice the life of the concrete which works to improve the treatment process through Improving bacteria, whose main supporter is the food of bacteria and current studies show that injecting with Nano-tech helps to increase the amount of food inside the concrete and this supports the properties of bacteria by speeding up the healing processes and improving the permanence. However, self-healing is not only for concrete but for the oil tank and communication cable that builds a strong world in the properties processes of materials that make materials' structure strong, improved and higher permanently, and this helps to look for performing self-healing treatment. [5, 29, 35].

3.2.5 Implemented Buildings by using Self- Healing concrete in the United Kingdom

Self-healing concrete technology represents the technology of the modern era in the cement industry sector. In the United Kingdom, it is considered the first prototype that was tested on the retaining walls and is considered a prototype from which the concrete mixture was made. It contains bacteria spores that are placed inside the concrete mixture which is considered the prototype. The restoration of a water tank tower, which is considered one of the ancient buildings, has been completed and it is considered the first concrete structure in Malta, where the treatment method was used with smart concrete materials, including self-healing materials, in order to give durability and higher strength. [36, 37].

3.3 Construction Market Perspective from New Concrete Technology

Continuous development in the field of growth in the cement industry market opens the way to growth in concrete products and developments as the cement industry and its products market are considered an important economic field in every country which contribute to its growth and development. Therefore, self-healing concrete is considered a crucial product in the field of growth for the cement industry because it will strengthen purchasing and exchanges to increase the financial returns significantly on the cement industry. The development in concrete products, which resulted in self-healing concrete contributes to increasing purchasing power, and this helps in achieving the results of growth for the concrete industries sector. The economic strength of the self-healing concrete product is handled for five years by (24 to 26%), and this indicates the increase in investment in the cement sector and cement technology fields. [8, 9, 38, 39].

3.3.1 Internationalization New Concrete Technology for Market

The technological development in the field of cement industry, which was centered on the development in the field of self-healing concrete and the entry of technology to the global market contributed to an impact on other products that are manufactured in the cement products sector and its effects on the global market, which contributed to reducing and saving costs in the construction and infrastructure sector contributed to the increasing growth and prosperity in the self-healing concrete sector. For instance, it positively affected the purchasing power, which also contributed to the growth of global investment in the cement sector which created a gap in the cement sector, accordingly, this new technology helped in increasing growth to fill market needs gaps that came to satisfy the market's desires in its contribution to investment growth in developing technology that keeps pace with market needs. [8, 9].

3.3.2 UK Construction Market and Perspective to Self-Healing Concrete

The United Kingdom market is one of the most economically thriving markets, but the impact on the construction sector needs to be developed continuously. One of the reasons for the differences that were made by self-healing concrete in the United Kingdom market is the development in the cement products sector. For example, the largest cement company, CEMEX factory, which works on developing the concrete product self-healing and strengthening the engineering market in the engineering construction and contracting sector, which contributes to increasing the purchasing power of cement products. This helped strengthen the export sector of the self-healing concrete, which was a point of attracting investors from abroad to the continuous development in the sector cement. Self-healing concrete has witnessed a rapid growth and will increase from 24 to 26% in the five coming years. This is an indication of the growth in the cement sector and its contribution in giving a competitive advantage in order to become a competitive force in attracting investors as well as the purchasing power of the sector cement industry. [38, 39, 40, 41].

3.3.3 Growth of Self-Healing Concrete in UK Construction Market

The cement industry market is constantly growing, and self-healing concrete keeps pace with the accelerating growth in the United Kingdom market and keeps up with the increase in the purchasing power of the cement factories. This opens up prospects for the manufacture and export of self-healing concrete to the external market where the purchasing power contributes to an increased growth for the United Kingdom market. This market provides all the needs of the neighbouring markets and is considered essential to meet the needs of the local and external markets of the United Kingdom, which will contribute to improving infrastructure and urban technological development as well as adding market advantages in terms of building materials for self-healing in order to improve the cement market, which

contributes to the increase in sales and both internal and external investment of the cement industry sector.[9 , 24].

3.3.4 Stainability for the Construction Market Cost

Contracting, construction, and building restoration sector in the United Kingdom spend "£ 40 billion" in order to restore and maintain buildings and rehabilitate public facilities. Since that the rate of costs is high and the annual maintenance and rehabilitation of facilities is done, self-healing concrete contributes to the United Kingdom market and is viewed as the best option for a balance of maintenance and restoration costs. It is seen as the best investment in the cement industry sector that reduces the costs of building maintenance and the durability and strength of the building. As high maintenance costs contribute to stimulating and increasing the economy regarding reducing costs and development in the cement sector, it is considered an economic catalyst to increase investment in the cement industry in terms of the maintenance and restoration of existing buildings that were affected significantly in the United Kingdom. All in all, the self-healing concrete has contributed to reducing costs significantly, resulting in improving the economic side that is purely in the sector improved facilities in the United Kingdom. [3, 8].

3.3.4 The companies' market of developing concrete products self-healing in the UK

JP Concrete is considered one of the leading companies in the UK, which has collaborated with Basilisk to supply its new product, which contains self-healing materials that are mixed into precast concrete that contributes to giving strength and durability to precast concrete products. Whereas the self-healing Basilisk concrete contains bacteria inside the precast concrete or ready-mix concrete, it is activated upon contact with air and water and upon the occurrence of cracks in the concrete, which contributes to the activation of bacteria and closing the cracks that helps in preserving the concrete structure from any factors that reduce the efficiency of concrete. [36, 42].

3.3.5 Industrial Analysis of Construction Market for New Concrete

Self-healing concrete entered the global market and the United Kingdom market in the field of cement industry. It is considered a new technology in engineering, building construction and restoration market. It is also an important step in the cement industry that increases the opportunities for cement markets, and this gives a great impact in order to be an opportunity to analyse the cement industry market and the impact of self-healing concrete as well as growth witnessing this industrial wealth in the sector of maintenance and restoration of buildings. [12].

3.3.5.1 PESTEL Analysis

Table 1: PESTEL [7, 9]

PESTEL	
Political	It depends on the building system and building codes in the United Kingdom and the state policy in the growth of construction projects and urban prosperity in the region.
Economic	An effect on the economy in the cement industry sector that works on the effect of a significant difference in growth and where it contributes to the continuous development of the building construction sector and this effect contributes to the economic growth of the region.
Social	The continuous development in the cement industry sector opens up prospects for increased demand in human resources, and this affects a community, which contributes to providing job opportunities and reducing unemployment.
Technological	The technology is self-healing concrete that has the characteristics of a live concrete that contributes to self-closing cracks when the right environment is available.
Environmental	Self-healing concrete is a technology that has evolved to provide environmental solutions and is considered a sustainable building development.
Legal	Building law is interested in technological development and there are provisions and details that support this development in United Kingdom building law.

3.3.5.2 Porter's five Forces Analysis

Competitive Rivalry

Strong competition makes the value of self-healing materials increase in the market, and this contributes to an increase in purchasing power, which allows the market's ability to be competitive companies. [7].

Supplier Power

Spreading sales and supplier's executives at the same time contributes to product development because it reaches all customers and knows the needs that customers need and where the self-healing process contributes to giving quality and durability in the process of repairing cracks. [40].

Buyer Power

Customer gain and meeting customer desires contribute to purchasing power and self-repairing concrete products contribute to meeting customer needs, which contribute to strengthening relationships between the buyer and the self-healing product. [8].

Threat of Substitution

Accelerating growth requires continuous development in concrete products, s as well as increasing the volume of investments and attracting investors, and this contributes to accelerating the production and export process. Accordingly, resulting in increasing purchasing power, distinguishing its customers and meeting their needs. [7].

Threat of New Entry

The new entry of a product into the market for the cement industry; self-healing concrete products, works to improve the economic strength of the cement industry and contribute to the increase in investment in self-healing products, resulting in a continuous development in concrete technology which is considered a strong threat to enter any new product to the United Kingdom companies. [3, 8].

3.3.6 Market Construction Strategy

The market relies on many strategies in order to introduce new technological materials in the field of building construction. However, manufacture of cement materials is one of the most important axes of economic change and the use of self-healing products adds many advantages to the cement industry market, which is a strength point in improving purchasing power and developing mechanisms to attract investors. In other words, the growth in the field self-healing concrete is a profitable growth in its investment, and as the product growth will increase from 24 to 26% over the coming years, this helps in building a market to start incorporating new strategies that work to study the market and then it is put in a stronger way to be a strong source and factor in the field of cement industries. [8, 22].

Table 2: Market Segmentation [39]

Demographic Segmentation	**Behaviour Segmentation**	**Geographical Segmentation**	**Psychographic Segmentation**
It depends on the construction sector, contracting and the financial ability to buy.	Attracting customers to advanced cement products is what changes the customer's behaviour in the market.	The United Kingdom has a unique geographical location that can contribute to the purchasing power of the surrounding areas.	The psychological factor of the product, which contributes to the increase in purchasing power among customers, to increase the permanence and self-healing of cracks.

Table 3: Market Mix (4P's) [3, 8, 12]

Product	**Pricing Strategy**	**Place**	**Promotion**
Self-healing concrete is a characteristic of the product in the self-healing cement industries.	The price strategy depends on the area in which it is spreading, the purchasing power and customer needs.	The appropriate place of manufacture and procedures that are compatible with the environment.	Meeting the needs of customers that support and contribute to the increase in consumer products of the cement industry as well as the purchasing power of the product which contributes to the increase in the marketing power of the product.

3.4 Self-Healing Concrete Influence on the Durability of the Building

Buildings are exposed to cracks, which can affect the building's permanence and contribute to weakening the strength of the structure, which can cause cracks to fail in one of the construction systems. This is where the self-healing concrete contributes to the strength and durability of the building and works to improve the life span of the engineering design. There are multiple forms of self-healing factors that are set in various places, including the oil stations that are built and which consist the concrete into the components of self-healing in order to give durability to the facility. In addition to the power transmission cables that are used for internet. Furthermore, the materials that have been combined

with the properties of self-healing gain strength and durability and increase construction efficiency, which increases the hardness of the loads that have been mixed with the components of self-healing in buildings contributed to increasing the efficiency and protection of the rebar. Accordingly contributing to the development and improvement of the cement industry and the boom in cement technology. [35, 43].

3.4.1 The Impact the of Self-Healing Concrete on the Strength and Efficiency of the Building

Self-Healing concrete contributes to improving the durability of the treated surfaces, which improves the building's strength completely, and this affects the strength that will contribute to other changes regarding the absorption and permeability of the water into the concrete. However, the quality of the material of self-healing concrete is viewed in key parameters including, compressive strength, permeability, and corrosion. Reinforcement steel, as it indicates, is self-healing concrete to improve the durability of concrete structures and the environmental adaptation of the bacteria, which contributes to the sustainability of the building in the buildings that do not exist, and this will help to enhance the environmental protection of the buildings. In general, self-healing concrete is considered environmentally friendly and the effect of concrete with self-healing compounds is apparent on cracks and in its ability to treat cracks in a period of time that can build bacteria and self-healing compounds that contribute to the self-healing process and that improve the building's ability to withstand environmental conditions that is affected by moisture, cracks, water permeability, intolerance to pressure and loads. [10, 44].

3.4.2 Durability and Stainability of Self-Healing Concrete in Buildings

Self-healing compounds work on giving durability to the structural model, and this helps in obtaining durability with reference to building material specifications. This contributes to ensuring hardness and water permeability to the reinforcing steel that contributes to strengthening concrete immunity in order to work regularly and with high efficiency when cracks weaken concrete and lead to many problems, including iron rust. Therefore, self-healing compounds enter the self-healing concrete in order to play a large and effective role in closing the cracks and give the concrete sufficient effectiveness to protect the rebar and prevent the permeability of the water that is considered in the existing buildings that leads to weakening the concrete and durability of concrete in existing buildings which contributes to the sustainability of buildings. [19, 45].

3.5 Objectives of Research

Research objectives are summarized in several matters, including improving the purchasing power of cement industries, which contributes to improving the market environment building construction and the engineering contracting market for construction. This helps to contribute to attracting investors because self-healing concrete reduces maintenance and rehabilitation costs as self-healing processes proves a high ability to close cracks. Consequently, resulting in increasing the concrete's durability and supplying the concrete with self-healing compounds that contribute to improving the efficiency of the concrete compounds as well as improving the concrete shelf life of the design in the beginning so that the effect of self-healing compounds on existing buildings does not exist. It rather contributes to improving the sustainability capacity of buildings, improving building efficiency and reducing damage, whether from the building or from the costs that contributed to increasing the concrete market to growth in global markets. [5, 19, 38, 39].

4 Analysis

The analysis works on clarifying the methods and the goals of the research. In addition, the studies incorporated in this study are approved among the literary studies that contribute to the quality of the research. The analysis in this study also contributes to ensuring the quality of the studies that were chosen from the databases. It also refers to scientific literary references or studies from high-quality articles that contribute to the development of the research, which will contribute to improving and developing the parts of the analytical studies of the research objectives, research question, and literary references.

4.1 Research Data Analysis

Research studies constitute its dependence on secondary data from different scientific researches and studies approved by the University of Bedfordshire and the Middle East University. The studies tackle topics of self-healing from the cement industry and concrete development as well as its impact on market study building construction and construction in general, which show the thriving growth of self-healing concrete. This research includes thirty researches that were reached accurately from the research study, the source and name the author, the database, and the website from which the research was taken and scientific study is one of the areas of the minute that guarantees the research category and which it was filtered accurately from identifying resources, authors, and articles that include the cement subject of self-healing. This study follows researches and developments on the field from (2004) to (2020) and chooses those keywords:(self-healing concrete), (United Kingdom), (construction market perspective), (durability), (permanence of

the building) which were in the databases that were accessed for research studies from the following databases: Emerald, ScienceDirect, Ebsco, ResearchGate, Google Scholar, and the databases on which where the research was based on qualitative methods and used secondary data (systematic review methodology).

4.2 Analysis of Studies

This research includes studies which have been detailed and discussed the effect of self-healing concrete in the world of cement industry. These scientific studies revolve around the impact of self-healing concrete and self-healing compounds that make up concrete and how it affects cracks. They also discuss the process of self-healing, which is centred on how it effects on existing buildings and how to mix concrete and inject cracks in self-healing materials and discuss self-healing technology uses other than cement industry, which are building self-healing compounds for continuous technological development. The studies that are placed in the United Kingdom and focus on the uses of self-healing and its impact on the buildings and the cement industry where the studies pointed to the impact of the United Kingdom market in the self-healing concrete industry, which included reducing the costs that were found from the restoration and maintenance of the buildings erected and providing financial costs in the market building construction and engineering contracting. The studies also highlighted the role that self-healing concrete will play in the economic growth in the coming years, which will reflect this development in the cement industry sector. Finally, its impact on sustainability which is largely reflected on the impact of non-existing and existing buildings so that the increase in durability and strength of concrete and the life span of the construction structure and the improvement of the concrete components and the protection of rebar from external environmental factors and the erosion of iron and contribute to reaching a safe environment for buildings through the manufacture of cement for self-healing compounds. [3, 8, 22].

4.3 Analysis of Research Questions and Objectives

The objectives of the research discuss self-healing concrete and its impact on the United Kingdom. It also incorporates the studies and accurate scientific research in the United Kingdom that include that the effect of self-healing concrete on existing and non-existing buildings and was among the categories of objectives research is to obtain the sustainability, strength and durability of buildings as well as maintaining existing and non-existing buildings by mixing cement mixtures with self-healing compounds. One of the research goals is to show the ability of self-healing concrete to spread and grow in the United Kingdom market which remarkably increased purchasing power, growth in the cement industry, as well as the cement market booms, which contributes to attracting investors and growth in self-healing compounds. Furthermore, research questions and objectives are linked to research in the scientific research and studies that have been reached that contribute to the development of the cement and concrete industry Self-healing.

5 Discussion

5.1 Self-Healing Concrete Technology

Self-healing in the cement industry and self-healing compounds play an important role in the cement industry and technology contributed to the development of the cement industry and were able to make a difference in the field. The self-healing compounds are mixed inside the concrete elements during mixing, including cement, mortar, water and self-healing compounds consisting of bacteria bacillus subtilis bacteria which feeds on calcium lactate. The food of bacteria or spores contributes to stimulating and the cycle in the concrete, it also works to enhance the action of bacteria inside the concrete. Moreover, it increases the action of bacteria inside the concrete when the appropriate environment is available to close the cracks within a group of concrete operations in order aimed at the closure of cracks and protect the internal parts of the concrete. [20, 22].

5.2 Self-Healing Concrete Performance on Buildings

The technological performance of self-healing concrete in buildings contributes to the development of crack repair operations in buildings, whether existing or not, so it will be an opportunity to improve buildings and their durability, which permits buildings to maintain the reinforcing iron from corrosion and increase the percentage of bearing of concrete more. Therefore, it helps to increase the sustainability of self-healing concrete in order to decrease the weakness of building permanence and improve the internal qualities of concrete and the built structure. It offers an opportunity to preserve buildings that are a strong motivation for the restoration and maintenance of buildings from the properties of concrete in a self-enhancing way that enhances the characteristics of self-healing concrete to resist changes which It covers buildings whether changes inside the building such as cracks or changes that result from the surrounding conditions of the building. [20, 31].

5.3 UK Construction Market Perspective on New Concrete Technology

The United Kingdom market was positively reflected by developing and improving the products of the cement industry

as the new technology contributed to the growth in the cement and concrete markets in the United Kingdom. Accordingly, growth was increasing, which contributed to satisfying the desires of customers and customers at the cement factories and the market of building construction and maintenance. This resulted in an increase in the purchasing power, urban movement, and development. The continuity in modern technology has contributed to raising the purchasing power and the desire to invest in the cement industry market which this indicates the increasing growth in the coming years, which will witness the movement of the market in the United Kingdom in the process of reflecting the impact of technology, a modern self-healing technology that contributed to reducing costs on the other hand and resulting from the process of building maintenance in order to contribute to the efficiency of the cement industry and concrete technology sector in the building construction sector and the cement industry and ready-mixed concrete sector. [8, 22, 41].

5.4 Impact the Self-Healing Concrete in the Cement Industry of the UK

The development of technology has a great impact on the cement industry market. For instance, the installation of self-healing concrete is a huge scientific development which played a very important role in the cement industry in the United Kingdom market. This contributed to the acceleration of the spread process and expanded the movement of self-healing concrete in the purchasing power of the cement sector as well as the expansion of export of products. Cement is widely used around the United Kingdom scale, accordingly, the buying power and attracting investors in the cement sector contribute to further improving and developing the cement sector. This improvement is reflected on the United Kingdom market in the cement industry, as it is considered an opportunity for business growth and sustainability in production in the cement industry sector and turned into an opportunity for medium-sized companies to spread in developing strategies and improvement in the cement sector. [40, 41].

5.5 Companies involved in the development of self- Healing concrete in the UK

The interest in the self-healing concrete industry began as the annual building maintenance cost ratios on an ongoing basis, so the joint agreements began between the Basilisk company to supply its product to the JP Concrete company in the United Kingdom, where the company specialized in precast concrete that has higher strength and durability and when mixed in self-healing materials the hardness, durability and self-curing of concrete will be greatly improved. As the demand for concrete technology products increased, competition between the emerging companies entered the cement industry markets, and since Mimicrete is an emerging company in the field of materials technology from Cambridge University, it obtained a financial grant to develop its products in order to match the British market, and it has been working with JP Concrete to develop Concrete technology and provide the concrete product with self-healing materials where self-healing concrete will contribute to the healing of the concrete cracks once there are cracks in the concrete when exposed to external factors. Since self-healing concrete was designed and produced to prolong the concrete life and durability of concrete, it will increase the strength of the concrete component, which will lead to a reduction in maintenance costs for construction buildings. [46, 47].

5.6 Theories of Research

Technological development in the cement industry, which is considered an economic wealth in the world, i.e. self-healing concrete has contributed to the growth and prosperity of the cement sector. Therefore, the economic theory has impeded the principle of the growth of the cement sector and self-healing concrete products where growth will flourish in the next (24 to 26%) years, which contributes to saving millions in the building construction sector. This will support other theories, including market theory, which shows the advantages of the products of the self-healing concrete product that competes to save financial costs and also improve the quality of concrete. This contributes to adding to and improving properties concrete, such as giving durability and strength to the concrete structure, thus, giving a strong impetus to the increase and prosperity in the purchasing power in self-healing concrete products. When self-healing concrete acquires strength, this gives it the advantage by which it competes in the market and the industry sector, which supports the investment theory and brings investors to the industry sector from the scientific theories. Self-healing compounds consist of the most important bacteria and bacterial food, which can be either spore in the incubation period, where the bacteria is rehabilitated to the concrete environment, therefore, enhances the growth period within the concrete and the cracks are closed when they get an appropriate environment for growth and closure and interior restoration of concrete, which gives strength, durability and increases the properties of the structural structure. It also contributes to protecting the internal armature from the external and internal influences of the buildings. [1, 5, 8, 38, 40, 50].

5.7 Discussion with other studies

There are several studies that discuss self-healing concrete. Whereas some studies were directed to raise issues of self-healing concrete development and how to market orientation and benefit from self-healing materials, other studies

highlighted the importance of self-healing materials in reducing maintenance costs and raised several topics about revitalizing self-healing materials and how to homogenize the environment of bacteria inside the concrete. The studies also discussed the time period and durability and the results that can be obtained when using self-healing materials and their importance to the market in terms of reducing maintenance costs as well as giving a higher life span of concrete through improving the properties of concrete. On the other hand, this study sheds light on the development of self-healing concrete around the market, which has been specialized in the UK market, as well as the self-healing mechanism for existing and non-existing buildings. In addition, it introduces companies that began to open their markets in the United Kingdom as well as the importance of self-healing materials in the industry. [48, 49, 51, 52].

5.8 Literature Gap

The interest of the research gap is related to the research question, which revolves around the impact of self-healing concrete on the market and the nature of the material as well as its impact on buildings. Furthermore, the research studies this positive impact to bridge the research gap by increasing growth in the cement sector in the industry (United Kingdom) in terms of market and growth in the purchasing power of self-healing products. On the one hand, self-healing is one of the stages of development that contributed to the growth of the cement sector that contributed to the prosperity of bringing in investment, which resulted in bridging the market gap for the self-healing concrete industry sector. On the other, it studies its scientific side, where it contributed to the increasing building strength, preserving the internal structure, reinforcing steel, and merging concrete with self-healing. Hence, increased the sustainability of both existing and not existing buildings. This contributed to bridging the study gap through its impact on buildings and the construction sector of buildings where the process of self-healing increases the prosperity of buildings and works to protect against external and internal impacts. [1, 20, 31, 52, 53, 54, 55]

5.9 findings

The studies that have been discussed in this research confirm the positive impact on the United Kingdom market where the market distinguishes the cement industry from purchasing power and investment, which contributes to reducing costs in the world of construction market and engineering construction. This is one of the aspects which we talked about along with discussing the effect that occurs on the buildings when combined with the elements of self-healing concrete, which gives the building strength, durability and toughness as well as contributing in protecting the interior parts of the building from damage caused by the iron rust. Since the research gap is what the research question was searching for through the effect of self-healing concrete and that gave a positive effect on bridging the research gap by increasing growth in the cement sector in terms of the market. Whereas studies from scientific journals considered self-healing as one of the stages of development that contributes to the prosperity and growth of the cement sector, this research helps to bridge the market gap that contribute to the prosperity of purchasing power and the growth of a new investment sector where building strength and permanence of the building has increased, which is considered one of the aspirations of technology that works to develop the cement sector to the sector prosperous. This research is expected to add to the scientific community by taking another look in terms of integrating the market sector and the impact on buildings where technology has not been integrated into the business world. To conclude, self-healing concrete is considered a great opportunity in the world of business and technological development. Therefore, this research hopes to add to the aspiration to growth and investment in the cement and linkage sector of concrete technology, which is the living concrete (self-healing concrete) that will contribute to the creation of a new world for the coming years in the world of cement industry. This research will help researchers and investors who are interested in the field of cement technology where the self-healing concrete industry has become increasingly prosperous and growing, which also increased purchasing power through implementing different research strategies that rely on related literature that highlight the recent developments in the world of concrete and structure.

6 Conclusion and Recommendations

6.1 Conclusion

Cement is considered one of the most important economic matters, as it is considered primarily in the sector of building construction, engineering contracting and technological development in cement. It is a self-healing concrete installation that contributes to a qualitative shift in the cement industry sector, which results in reducing costs significantly in terms of maintenance of facilities. It also expands and spreads to create strongly increasing purchasing power and prosperity in the production of self-healing concrete industry in the United Kingdom. Moreover, it contributes to strengthening investment and bringing in external investment in order to be a strong economic wheel in the cement sector as the research indicates. In other words, the impact of self-healing concrete in the cement and construction industry sector, which is viewed in terms of science as having a positive impact on sustainability in terms of economy and marketing. Furthermore, its effect on existing buildings is seen through its ability to protect the internal structure from external

influences, which is the internal armature of one of the most important internal parts in the existing buildings when cracks occur under the effect of moisture. Here, the role of bacteria comes, which is an important part of the self-healing process, with the presence of the appropriate environment, the process of closing cracks starts. However, the effect on existing buildings is not clearly explained in research and scientific studies, this is where the role of this research starts. It is interested in improving and accuracy of research quality, including studies that are specialized in studying the effect and behaviour of self-healing concrete and its impact on the internal parts of the structure. This contributes to improving and communicating important points in this research, as well as its positive impact in filling the research gap by studying the impact of self-healing concrete in terms of market and economic terms and a boom in growth in the sector self-healing concrete industry.

6.2 Recommendations

Among the research studies and the result of this research are the recommendations that have been reached by which the research contributed to reaching through cement technology and development properties in the self-healing materials interest in cement industries and self-healing concrete. In addition to the continuous development on self-healing compounds, which increases the strength of growth and prosperity in the cement industry. This prosperity contributes to improving investment in the cement sector and the self-healing concrete sector as well as giving medium-sized companies an opportunity to develop and grow in order to work with large companies in a participatory rather than competitive manner. Consequently, giving an opportunity for the economy in the self-concrete industry to spread and have prosperity and deal in a partnership with companies gives a strong opportunity for the market. This gives a competitive advantage to spread through maintenance and improvement in the restoration of facilities and all concrete structures, which contributes to the improvement of the original characteristics of the self-healing concrete and the improvement of bacteria, which gives strong properties in closing cracks through improving products supporting food for bacteria and improving the internal structure of bacteria. Accordingly, giving an opportunity for research centers to reach many experiences not only in concrete compositions but rather to reach self-healing in all solid materials, which gives economic strength in the world of materials. This is added to the end of the recommendation in the search for self-healing concrete and self-healing materials from a new technology in materials, which will help to reach future goals in spreading, whether economic or scientific. This scientific achievement in reaching to improve self-healing combinations in a participatory manner in which bacteria and internal materials have been indicated, help scientific research in continuous future development that contribute to strengthening the scientific gap and scientific research.

7 Declarations

7.1 Author Contributions

Conceptualization, N.R.; methodology, N.R.; validation, N.R. and H.AS.; formal analysis, N.R.; investigation, N.R.; resources, N.R.; data curation, N.R.; writing—original draft preparation, N.R.; writing—review and editing, N.R. and R.O. and H.AS.; visualization, N.R.; supervision, H.AS. and R.O. All authors have read and agreed to the published version of the manuscript.

7.2 Data Availability Statement

The data presented in this study are secondary data from scientific studies in the databases. The studies presented in this study are included in the appendix.

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Conflict of interest

The authors declare that there is no conflict regarding the publication of this paper.

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Appendix

Methodological Studies

Table 4: Methodological Studies

#	Authors	Name of article	Relevant
1	Aïssa, B. (2014)	Self-healing Materials: Innovative Materials for Terrestrial and Space Applications. Smithers Rapra.	Relevant
2	Al-Tabbaa, A., Litina, C., Giannaros, P., Kanellopoulos, A. and Souza, L. (2019).	First UK field application and performance of microcapsule-based self-healing concrete. Construction and Building Materials,	Relevant
3	Angst, U. M. (2019).	Correction to: Challenges and opportunities in corrosion of steel in concrete. Materials and Structures	Relevant
4	BROWNELL, B. (2011)	Self-Healing Concrete', Architect	Relevant
5	Baera, C., Szilagyi, H., Pastrav, M., & Mircea, A. (2014).	Self-healing behavior of concrete cracks. Concrete Solutions	Relevant
6	Cardiff University. (2020).	UK's first trial of self-healing concrete.	Relevant
7	Cement.mineralproducts.org. (2020).	Mineral Products Association (MPA) Cement - representing the UK cement industry.	Relevant
8	Corradi, M. (2019).	Experimental Study of Self–Healing in Reinforced Concrete Flexural Elements.	Relevant
9	Corradi, M. (2019).	Experimental Study of Self–Healing in Reinforced Concrete Flexural Elements.	Relevant
10	De Rooij, M., Van Tittelboom, K., De Belie, N., & Schlangen, E. (Eds.).	Self-healing phenomena in Cement-Based materials: state-of-the-art report of RILEM technical committee 221-SHC: self-Healing phenomena in Cement-Based materials	Relevant

	(2013).		
11	Dunn, S. C. (2010).	An novel self-healing shape memory polymer-cementitious system	Relevant
12	Forde, C., & MacKenzie, R. (2007).	Concrete solutions? Recruitment difficulties and casualisation in the UK construction industry.	Relevant
13	Formia, A. et al. (2016)	'Experimental analysis of self-healing cement-based materials incorporating extruded cementitious hollow tubes'	Relevant
14	Jonkers, H., Thijssen, A., Muyzer, G., Copuroglu, O. and Schlangen, E. (2010).	Application of bacteria as self-healing agent for the development of sustainable concrete.	Relevant
15	King, A. (2013)	'Self-healing concrete', Chemistry & Industry	Relevant
16	Lin, H. et al. (2019)	'Imparting water repellency in completely decomposed granite with Tung oil', Journal of Cleaner Production,	Relevant
17	Future, M. (2020).	Self-Healing Concrete Market Expected to Grow at a Striking Pace of 24% CAGR Through 2024	Relevant
18	Gardner, D., Lark, R., Jefferson, T. and Davies, R. (2018).	A survey on problems encountered in current concrete construction and the potential benefits of self-healing cementitious materials. Case Studies in Construction Materials,	Relevant
19	Globalconstructionreview.com. (2020).	Concrete, heal thyself: UK firm pilots new breed of material that could save billions - News - GCR.	Relevant
20	Hazelwood, T., Jefferson, A., Lark, R. and Gardner, D. (2015).	Numerical simulation of the long-term behaviour of a self-healing concrete beam vs standard reinforced concrete.	Relevant
21	Hazelwood, T. (2015).	Investigation of a novel self-healing cementitious composite material system	Relevant
22	HILL, D. (2013)	'U.K. Research Team Developing Concrete That Heals Its Own Cracks', Civil Engineering	Relevant
23	Harbottle, M. J., Lam, M. T., Botusharova, S., & Gardner, D. R. (2014).	Self-healing soil: Biomimetic engineering of geotechnical structures to respond to damage.	Relevant
24	Ibisworld.com. (2020).	IBISWorld - Industry Market Research, Reports, and Statistics.	Relevant
25	Journal of Commerce. (2020).	Dutch scientist invents self-healing concrete with bacteria - constructconnect.com - Journal of Commerce.	Relevant
26	Lucas, S. S. et al. (2016)	'Study of quantification methods in self-healing ceramics, polymers and concrete: A route towards standardization', Journal of Intelligent Material Systems & Structures	Relevant
27	Luhar, S., & Gourav, S. (2015).	A review paper on self-healing concrete.	Relevant
28	Osborne, J. (2019)	Self-Healing Concrete Could Cut Costs', Professional Engineering,	Relevant
29	Okude, N., & Shiotani, T. (2019).	Application of Surface-Wave Tomography to Sealed Conditions of Repaired Cracks in Concrete.	Relevant
30	Orca.cf.ac.uk. (2020).	An novel self-healing shape memory polymer-cementitious system. -ORCA.	Relevant
31	Paine, K. (2016).	Bacteria-based self-healing concrete: Effects of environment, exposure and crack size.	Relevant

32	PR Newswire (2019)	'Self-healing Concrete Market by Type by End User: Global Opportunity Analysis and Industry Forecast, 2018 - 2025'	Relevant
33	PR Newswire (2019)	'Self-healing Concrete Market to Reach $1,375.08 Bn, Globally, by 2025 at 26.4% CAGR: AMR',	Relevant
34	Qian, C., Chen, H., Ren, L., & Luo, M. (2015).	Self-healing of early age cracks in cement-based materials by mineralization of carbonic anhydrase microorganism.	Relevant
35	Silva, F. B. et al. (2015)	Industrial application of biological self-healing concrete: Challenges and economical feasibility'	Relevant
36	Souza, L. R., Kanellopoulos, A., & Al-Tabbaa, P. A. (2015, June).	Synthesis and characterization of acrylate microcapsules using microfluidics for self-healing in cementitious materials.	Relevant
37	Teall, O, Davies, R. Pilegis, M., Kanellopoulos, A., Sharma, T, Paine, K.& Al-Tabbaa, A. (2016).	Self-healing concrete full-scale site trials. In *Proceedings of the 11th fib International PhD Symposium in Civil Engineering*	Relevant
38	Ukconstructionmedia .co.uk. (2020).	Self-healing concrete under development - UK Construction	Relevant
39	Vijay, K., & Murmu, M. (2020).	Experimental Study on Bacterial Concrete Using Bacillus Subtilis Micro-Organism	Relevant
40	Zhang, Z., Weng, Y., Ding, Y., & Qian, S. (2019).	Use of Genetically Modified Bacteria to Repair Cracks in Concrete. *Materials*,	Relevant