Benefits Realization and Application Challenges of Green Concrete Towards Sustainability in Saudi Arabian Construction

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Abstract. In recent years, Carbon Dioxide (CO2) emission has been increased by 22% in Saudi Arabia, and the building construction sector is one of the major contributors to increased CO2. This necessitates Saudi Arabia's introduction of energy efficiency and sustainability in the construction sector. Green Concrete (GC) has recently gained popularity in the Kingdom as it is environmentally friendly and produced from waste and residual materials. However, every new technology faces application challenges that can stymie its adoption in the industry. As a result, this study aims to determine the potential benefits and application challenges of using GC technology in Saudi Arabian's construction industry. This study conducted a comprehensive literature review of the subject followed by a questionnaire survey to field practitioners and interviews with professional experts to determine the potential benefits and application challenges of GC technology. In addition, an analysis of GC trail test documents implemented in a local project and a meeting with the project team were also conducted to determine the trial test's advantages and implementation challenges. The major benefits identified in this study are reduced energy use, waste material reuse, CO2 reduction, natural resource conservation, and reduced landfill numbers, while the major implementation challenges identified in this study are discouraging building codes and a lack of information and understanding of GC benefits. Subsequently, recommendations for government agencies, private sector businesses, and concrete suppliers are provided to improve the benefits of GC, resolve application challenges, and promote and accelerate its adoption in Saudi Arabia.

1. Introduction
In 2020, Saudi Arabia was ranked 11th in terms of overall primary energy consumption [1]. Buildings, industry, transportation, and utilities are among the sectors that lead to the inefficient use of primary energy resources. However, the building sector consumes approximately 28% of the Kingdom's primary energy [2] and emits 1% of direct CO2 emissions [3]. Currently, the Kingdom is undertaking numerous
construction projects in various sectors, including the building sector as part of its ambitious 2030 vision plan to shift the economy away from oil revenues by investing heavily in the construction industry. However, given the current rate of energy use, the amount of materials used, and the serious environmental impact caused by the construction industry, it is critical for Saudi Arabia to shift toward resource-efficient, energy-efficient, and sustainable buildings. This can be accomplished by using various green building technologies, such as, green concrete, eco-bricks, use of natural light, solar panel, etc., which provide a wide range of energy-resources efficiency and sustainability solutions. Many studies and research projects have examined the advantages and disadvantages of incorporating different green building technologies in the global and local construction industries [4]–[7]. Furthermore, previous studies on CG technology have focused solely on the technical benefits rather than detailing the challenges that can arise while using this technology. As a result, all types of benefits and application challenges associated with the local use of GC technology must be identified to promote its adoption in the Saudi construction market.

Thus, this study investigates the application challenges of green concrete and its intended benefits in the KSA's construction industry. This aim is achieved by addressing the following specific objectives: (1) to identify the various benefits of GC technology deployment in Saudi Arabia, and (2) to identify the various application challenges that are preventing GC technology implementation in Saudi Arabia. The findings of the study contribute to the construction professionals and the country's policy planners to comprehend the application benefits and challenges inherited to the GC. The remainder of the study is structured as follows: A literature review on green building technologies, GC technology, and GC benefits and application challenges is conducted, the methodology consists of data collection and analysis is discussed, the benefits and challenges of using GC technology in a local construction project are identified, followed by a discussion of the results, priority ranking of the overall defined benefits and application challenges, and conclusion and recommendations are outlined.

2. Literature Review

Green building is characterized as the practice of constructing buildings and implementing procedures that are environmentally friendly and resource-efficient throughout the building’s life cycle [8]. The US Green Building Council (USGBC) was established in 1993 with the aim of transforming the construction industry into one that is environmentally conscious. By 1998, the USGBC had created the Leadership in Energy and Environmental Design (LEED) scheme, which was the first to describe what green building entails, and there were 100 LEED-certified projects in the United States by 2004 [9]. The innovative and sustainable architecture of the King Abdullah University of Science and Technology campus received the first LEED certificate in Saudi Arabia in 2010 [10]; therefore, the green building sector is still relatively new in the Kingdom.

Conventional concrete manufacturing is very energy-intensive, owing to the cement, which makes up 12% of the concrete and consumes 94 percent of the total energy used [11]. Other concrete ingredients such as coarse aggregate, fine aggregate, sand, and water make up the remaining 6% [11]. The concrete production process is responsible for 4–8% of global CO2 emissions [12]. In the process of GC, a wide variety of waste and residual materials are being used as supplementary cement as binding material, indicating an alternative solution for the industry to achieve various benefits without compromising the mechanical properties of concrete. Khan [13] replaced 50% cement by fly ash to compare a normal concrete mix design with a green concrete mix design. Sakulich [14] reviewed the effect on concrete durability when using several SCM to replace cement such as slag, fly ash, silica fume, and rice husk ash. Esmaeili and Oudah [15] reviewed the utilization of recycled glass as a partial replacement to cement in ultra-high-performance concrete. Liew et al. [4] categorized the waste materials that can be used in the production of GC into three groups, namely industrial, agricultural, and municipal wastes.

2.1. Benefits of green concrete

Suhendro [6] listed three benefits of using GC, reducing carbon dioxide from the cement industry, reducing natural resources such as shale, clay, limestone, and natural rock, and using waste materials and by-products in concrete manufacturing. Błaszcyński and Król [7] highlighted no technology to
reduce the carbon dioxide emission generated by Portland cement manufacturing. However, the total amount of carbon dioxide can be mitigated by a range of 30% to 73% when incorporating different types of geopolymer cement in the production of concrete. Al-Mansour [16] pointed out that replacing cement with other environmentally friendly materials will reduce the CO2 footprint, enhance the physical and chemical properties of concrete, lower the overall cost of construction by lowering the materials cost, and minimize the number of landfills.

Table 1. Application benefits of GC

| No. | Benefits                          | Reference       | Category                  |
|-----|-----------------------------------|-----------------|---------------------------|
| 1   | Waste material reuse              | [6], [17]       | Environmental             |
| 2   | Reduces energy consumption        | [6], [16]       | Financial and environmental |
| 3   | CO2 reduction                     | [6], [7], [16]  | Environmental             |
| 4   | Improved Compressive Strength     | [16], [17]      | Technical                 |
| 5   | Natural Resource Conservation     | [6], [7]        | Environmental             |
| 6   | Reduces Landfill Numbers          | [16]            | Environmental             |
| 7   | Lower Material Cost               | [16]            | Financial                 |
| 8   | Reduced Project Completion Time   | [4]             | Technical                 |
| 9   | Improved Workability              | [4]             | Technical                 |
| 10  | Low Maintenance Cost              | [4]             | Financial                 |

2.2. Challenges of applying GC in construction
Suhandro [6] stated that discouraging building codes is a barrier to GC adoption. The key problem mentioned by Al-Mansour [16] was the need for long-term field tests to determine the reliability of using SCM in concrete. Insufficient field data, including long-term (20 years) durability data, standardization of GC in construction regulatory codes, more field applications are needed to understand better and experience GC. Besides, more research and development to promote the benefits of GC and encourage its adoption are also necessary [4]. Sakulich [14] pointed out the following challenges: lack of long-term durability data, lack of familiarity with and acceptance of GC, and lack of detailed life cycle analysis. Darko [5] identified multiple barriers to adopting green building technologies. However, some of these barriers are also applicable to GC, such as lack of incentives to universities, research institutes, and construction companies to pioneer the development and application of GC, lack of available and reliable suppliers, lack of database and information, resistance to change from the use of traditional methods, and lack of awareness of GC benefits.

Table 2. Challenges of using GC in building constructions

| No.  | Application Challenge             | Reference       | Category            |
|------|-----------------------------------|-----------------|---------------------|
| 1    | Discouraging Building Codes       | [4], [6]        | Governmental        |
| 2    | Lack of Long-Term Field Data      | [4], [16]       | Technical           |
Lack of Information and Understanding of GC Benefits [4], [5] Cultural

Limited Experience with The Use of GC [4] Technical

Resistance to Change from Traditional Concrete [5], [6] Cultural

Lack of Detailed Life Cycle Cost Analysis [14] Financial

Lack of Incentives to Pioneer the Development and Application of GC [5] Governmental

Lack of Available and Reliable Suppliers [5] Market

### 3. Methodology

In addition, a semi-structured interview approach was used to perform multiple interviews with local professional experts. The interviewees were given the opportunity to openly share their ideas and opinions after reviewing the lists of benefits and application challenges.

#### Table 3. Profile of the interviewee

| Interviewee | Business field      | Experience in green building construction (years) |
|-------------|---------------------|--------------------------------------------------|
| I-1         | Owner Representative| 4                                                |
| I-2         | Supplier            | 10                                               |
| I-3         | Designer             | 9                                                |
| I-4         | Designer             | 7                                                |
| I-5         | Designer             | 3                                                |
| I-6         | Project Manager      | 15                                               |
| I-7         | Designer             | 5                                                |
| I-8         | Project Manager      | 4                                                |
| I-9         | Designer             | 10                                               |
| I-10        | Designer             | 6                                                |

#### 3.1. Data analysis

The data gathered from the questionnaire survey and the case study will be (was) reviewed thoroughly and compared with the data obtained from the literature review before sharing it with the professional experts. Following the satisfactory completion of expert interviews, the list of advantages and implementation challenges were finalized. These factors were ranked to display the most relevant benefits and application challenges in Saudi Arabia. The ranking was done based on the maximum hits of each of the factors by the interviewees and the case study project. For example, if a single benefit or challenge was identified by eight interviewees, and also found in the case study project, then the score...
of that factor is nine (9). Alternatively, for a single benefit or challenge, maximum available score from the interviewees is 10 and maximum available score from the case study is one. Thus, altogether, this will be 11.

4. Result and Discussion
King Salman Energy Park (SPARK), Abqaiq, Saudi Arabia has deployed a newly developed concrete called "Podzolic Green Concert". Podzolic is the name given to the fine waste material generated from an asphalt concrete manufacturing plant. It replaces the Ordinary Portland Cement by 15% in the concrete mixes. The following table presents the Podzolic GC mix design as well as the design criteria requirements:

4.1. Case study
King Salman Energy Park (SPARK), Abqaiq, Saudi Arabia has deployed a newly developed concrete called "Podzolic Green Concert". Podzolic is the name given to the fine waste material generated from an asphalt concrete manufacturing plant. It replaces the Ordinary Portland Cement by 15% in the concrete mixes.
A meeting with the supplier and the SPARK Project Engineer was also held to better understand the advantages and challenges of using Podzolic-based concrete in the project. After 7 and 28 days of curing, the compressive strength exceeded the 28-day mix design criteria by 22.4 percent and 47 percent, respectively, indicating that the Podzolic GC compressive strength has improved. In addition, after a 90-minute time period, the slump was measured to be about 145 mm, and the temperature was measured to be 23 °C. This indicates the Podzolic modified concrete is easy to work with.
The water permeability of both Podzolic and Ordinary Portland Cement (OPC) mix designs was measured after 28 days of curing. The water penetration in the OPC concrete was approximately 62.3 mm, while it was just around 26.7 mm in the Podzolic concrete. As Podzolic concrete was compared to OPC concrete, the water permeability of the former was found to be around 43% lower. According to below DIN 1048-5 testing of hardened concrete standard, Podzolic concrete has a low permeability and thus will not corrode the reinforcement, resulting in lower maintenance costs and a longer service life. This waste material can also be used to replace a portion of OPC in concrete without weakening its mechanical properties. It also offers the possibility of making concrete more environmentally friendly by lowering CO2 emissions and repurposing waste materials in concrete. Furthermore, nearly 75% of asphalt concrete waste is dumped in municipal disposal areas (ref.); the use of Podzolic as a SCM in concrete helps to reduce this huge amount of solid waste and, subsequently reduces the overall landfill areas.
The overall output of Podzolic powder is estimated to be between 25,000 and 50,000 tons per year. As a result, a large quantity is available for use in concrete in the region. Furthermore, due to the availability of Podzolic powder in the local market, the cost of producing one cubic meter of Podzolic modified concrete is roughly equal to the cost of producing one cubic meter of OPC concrete. The benefits of Podzolic-based green concrete are shown in Table 4.

Table 4. Benefits of Podzolic-based GC

| No. | Benefit                        | Category                        |
|-----|--------------------------------|---------------------------------|
| 1   | Waste material reuse           | Environmental                   |
| 2   | Reduces energy consumption     | Financial and Environmental     |
| 3   | CO2 reduction                  | Environmental                   |
| 4   | Improved compressive strength  | Technical                       |
| 5   | Natural resource conservation  | Environmental                   |
| 6   | Reduces landfill areas         | Environmental, sustainable land use |
Local availability of reliable suppliers | Market, financial
Same OPC production cost | Financial
Low permeability | Technical
Low maintenance cost | Financial

Some application challenges are also identified from the case study regarding the use of Podzolic-based GC. These are listed in Table 5.

**Table 5. Challenges of using Podzolic-based GC**

| No. | Challenge                                                                 | Category                        |
|-----|---------------------------------------------------------------------------|--------------------------------|
| 1   | Discouraging building codes                                              | Governmental                    |
| 2   | Lack of information and education understanding GC benefits               | Governmental/academic           |
| 3   | Resistance to change from traditional concrete                           | Cultural and Knowledge gap      |

4.2. *Findings from experts’ interviews*

The findings from the experts’ interviews are listed in Table 6.

**Table 6. Responses of Experts evaluating each benefits**

| Category          | Benefit                                | Experts' responses |
|-------------------|----------------------------------------|--------------------|
| Environmental     | Water Material Reuse                   | ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ |
|                   | Carbon Dioxide Reduction               | ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ |
|                   | Natural Resource Conservation          | ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ |
|                   | Reduced Landfill Numbers               | ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ |
|                   | Reduces energy consumption             | ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ |
| Financial         | Lower Material Cost                    | - ✓ - ✓ - ✓ - ✓ - ✓ - ✓ - |
|                   | Improvement in Labor Productivity     | - ✓ - ✓ - ✓ - ✓ - ✓ - ✓ - |
|                   | Low Maintenance Cost                   | - ✓ - ✓ - ✓ - ✓ - ✓ - ✓ - |
|                   | Local Availability of Reliable Suppliers| ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ |
| Market            | Local Availability of OPC Substitute   | - ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ |
|                   | Same OPC Production Price              | - ✓ - ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ |
|                   | Improved Compressive Strength          | - ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ |
|                   | Reduced Project Completion Time        | - - - ✓ - ✓ - ✓ - ✓ - ✓ - |
| Technical         | Improved Workability                   | - ✓ - ✓ - ✓ - ✓ - ✓ - ✓ - |

6
The following are the main findings about the advantages of GC after the interviews were completed successfully: (1) All environmental benefits have been endorsed by all interviewees; (2) The environmental benefits, as well as the reduced energy usage benefit, are the most common; (3) Interviewees I3 and I6 pointed out that the financial and technical benefits differ depending on the form and percentage of SCM used in the mix design; (3) I9 suggested that the amount of SCM in the concrete mix design be increased from the current common 15-20%. This has the potential to maximize all environmental benefits, reduce energy usage, lower manufacturing costs, and possibly improve technical benefits, subject to further research.

By interviewing the same experts, the most common implementation problems are discouraging building codes and a lack of information and understanding of GC benefits. I6 disagreed with the application challenge of "lack of local OPC substitutes" and claimed that there are a number of waste and residual products that can be used locally. I2 noted that the technology is relatively new, especially in the Kingdom; as a result, long-term field data, comprehensive life cycle cost analysis, and experience with the technology are difficult to come by. I10 recommended that a local official green building institute should be created, similar to LEED in the US and ESTIDAMA in the UAE, to aid in the promotion of green concrete and other green building technologies. Since the market application was cancelled due to the case study's findings, the interviewees were not informed of the challenges.

4.3. Ranking of the benefits and challenges factors

Table 7 shows the ranking of the benefits of GC in Saudi construction field. Waste material reuse, natural resource conservation, CO2 reduction, reduces landfill areas, reduce energy consumption are some top-ranked benefits of GC in this country.

| Benefit                          | Interview score | Case study (yes=1, no=0) | Total score | Ranking |
|----------------------------------|-----------------|---------------------------|-------------|---------|
| Waste material reuse             | 10              | 1                         | 11          | 1       |
| Natural resource conservation    | 10              | 1                         | 11          | 1       |
| CO2 reduction                    | 10              | 1                         | 11          | 1       |
| Reduces landfill areas           | 10              | 1                         | 11          | 1       |
| Reduce energy consumption        | 10              | 1                         | 11          | 1       |
| Availability of reliable local supplier | 8              | 1                         | 9           | 2       |
| Lower material cost              | 6               | 0                         | 6           | 3       |
| Low permeability                 | 5               | 1                         | 6           | 4       |
| Low maintenance cost             | 4               | 1                         | 5           | 5       |
| Improved workability             | 5               | 0                         | 5           | 6       |
Table 8 shows the ranking of challenges of using GC in Saudi construction industry. Discouraging building codes, lack of information and understanding of GC benefits, and resistance to change from traditional concrete are top-ranked challenges of using GC in field.

| Challenges                                                      | Interview score | Case study (yes=1, no=0) | Total score | Ranking |
|----------------------------------------------------------------|-----------------|---------------------------|-------------|---------|
| Discouraging building codes                                    | 10              | 1                         | 11          | 1       |
| Lack of information and understanding of GC benefits           | 10              | 1                         | 11          | 1       |
| Resistance to change from traditional concrete                 | 8               | 1                         | 9           | 2       |
| Lack of incentives to pioneer the development and application of GC | 4               | 0                         | 4           | 3       |
| Lack of detailed life cycle cost analysis                      | 3               | 0                         | 3           | 4       |
| Lack of long-term field data                                   | 2               | 0                         | 2           | 5       |
| Limited experience with the use of GC                         | 2               | 0                         | 2           | 6       |
| Low permeability                                               | 5               | 1                         | 6           | 7       |

5. Conclusion and Recommendations
The possible benefits and implementation challenges of deploying GC technology in Saudi Arabia are investigated in this study. According to the findings, the top benefits are lower energy usage, reuse of waste materials, CO2 reduction, natural resource conservation, and a reduction in the number of landfills. This suggests that GC technology could provide a partial solution to Saudi Arabia's problem of rising domestic energy consumption and CO2 emissions. All these advantages demonstrate that GC is a promising technology that can easily replace traditional concrete in a wide range of construction projects. According to the findings, the most significant application challenges slowing the adoption of this technology in the Kingdom are discouraging building codes and a lack of information and understanding of the technology's benefits.

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