"Exploring Knowledge Gap in Geopolymer Concrete Adoption in the Dutch Construction Industry"

Thesis

Master Environmental and Energy Management

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Abstract

The increasing demand for infrastructure and buildings has resulted in the utilization of enormous amounts of concrete as the main construction materials. One of the main components of conventional concrete is cement which harms the environment since it leads to the emission of CO2. There has been an increasing demand for alternative sustainable materials to address this issue. Geopolymer (low-carbon) concrete is an alternative to replace conventional concrete. However, some barriers hinder their utilization such as lack of knowledge and low awareness of its application. The main objective of this study is to explore how the knowledge of professionals within the construction industry can influence the adoption of geopolymer concrete as a sustainable building material. To achieve this goal, diffusion of innovation theory (DOI) was set as a theoretical model, and specific steps of this theory were utilized. Qualitative analysis was used to explore the findings from semi-structured interviews with construction professionals. Participants specialize in the concrete industry with a high level of knowledge and expertise. Although their knowledge and awareness could not represent the whole construction industry, they referred to challenges regarding awareness about geopolymer concrete. The findings showed that younger professionals are more open to innovation because of their involvement with environmental issues and education. This is also the case with education where educated individuals better understand new materials applications since they are informed about relevant advantages. Analyzing responses for personality variables, including all three features of environmental, technological, and leadership skills is crucial to implementing innovative solutions. In addition, results highlighted the importance of formal channels like specific magazines, seminars, and informal communication such as social media and peer-to-peer recommendations to enhance information sharing. Moreover, the conservative nature of the construction sector hinders the adoption of innovative materials because of the competition. Companies are not willing to share detailed information about their specific materials. There are also concerns about regulatory frameworks, availability of materials, and prioritizing budget and time, hindering the adoption of new materials such as geopolymer concrete.

Keywords: Geopolymer Concrete, Sustainable Construction, CO2 Emission, Roadmap CO2, Circular Economy, Regulations.

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1. Introduction

This section provides an overview of sustainable construction materials focusing on geopolymer concrete and why it is selected, particularly within the construction industry. Besides, it describes the research objective, research question, and sub-questions to guide this study.

1.1. Background

The increasing demand for infrastructure and buildings has resulted in the utilization of enormous amounts of concrete as the main construction materials (de Azevedo et al., 2021). The production of concrete to meet the demand has already reached 15 billion tons globally where the rate of consumption is defined as one cubic meter for each person annually (Gartner, 2004). One of the main components of the conventional concrete material is ordinary Portland cement (OPC), which functions as a binder for other elements such as aggregates and fillers. This component harms the environment since it leads to the emission of CO2, as a major greenhouse gas (GHG) and exploitation of natural lime deposits (Akhtar et al., 2022). As a result, the emission of GHGs into the environment has been directly associated with global warming. From the materials accessibility perspective, the production of concrete presents overconsumption trends of raw materials to meet construction needs (Shahidan et al., 2017). Besides, the cement industry is known as being one of the sectors with major CO2 emitters, 8% of CO2 emissions globally are attributed to this sector (Farooq, 2021). To illustrate this problem, the amount of CO2 emission in million metric tons for main countries for period between 2005 to 2020 is presented in Figure 1 (Akhtar et al., 2022). As exhibited, there was a continuous increase in CO2 emission, which emphasizes the urging need to replace this material with less-carbon-emitted substitutes.

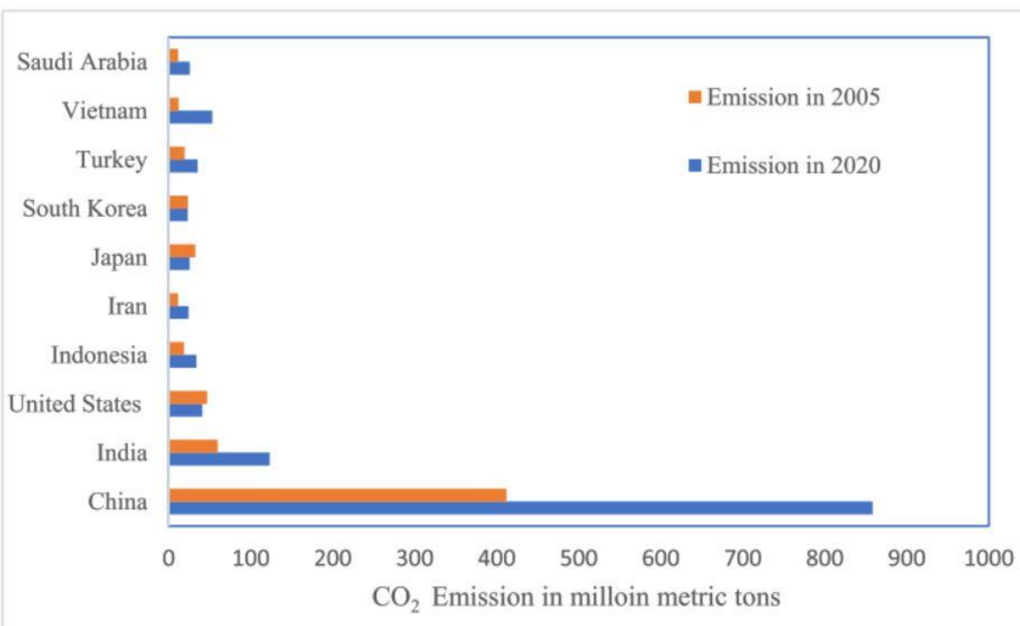

Fig. 1 CO2 emission by major cement-producing countries (Akhtar et al., 2022)

There has been an increasing demand for new materials that are more environmentally friendly and have less impact in terms of CO2 emission in the construction industry (Hassan et al., 2019). Regarding the given demand, geopolymers have been introduced as a sustainable binder to be replaced in the formulation of traditional cement to contribute to alleviating the CO2 emission issue while proposing eco-friendly disposal of waste materials (Akhtar et al., 2022). By using industrial waste materials instead of the raw materials found in traditional concrete, geopolymer concrete (GPC) potentially has multiple environmental benefits, which can be achieved by up to 80% in terms of CO2 emission reduction (Hassan et al., 2019). By incorporating waste materials such as ground granulated blast furnace slag (GGPBS) and fly ash (FA), GPC is considered as a promising alternative where it contributes to providing sustainable solutions related to the use of traditional concrete in the construction sector. The schematic process of GPC production consisting of waste materials along with an alkaline solution is illustrated in Fig. 2.

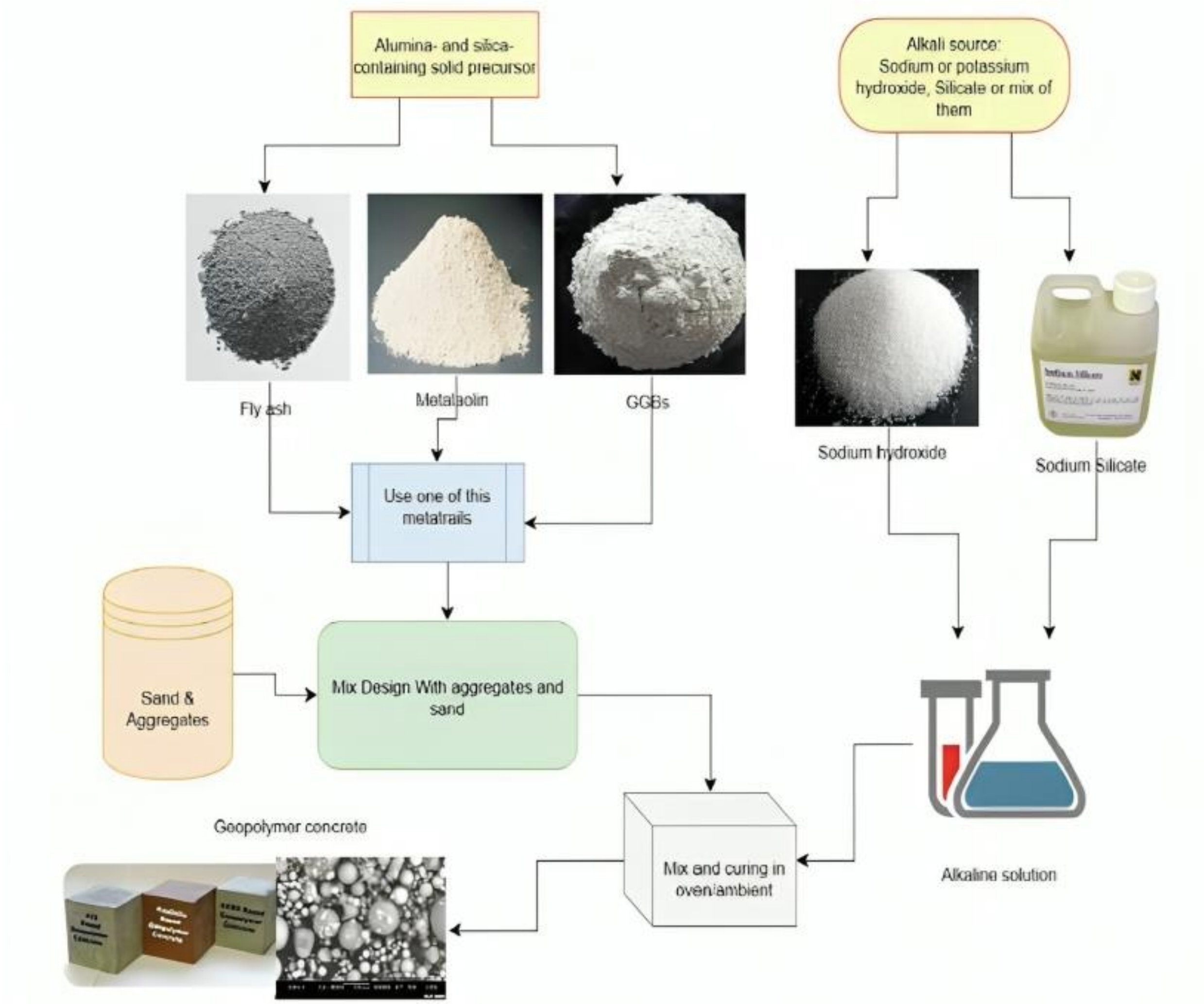

Fig. 2 Schematic process of GPC production (Hassan, 2019)

Therefore, utilizing geopolymer concrete in the construction industry is well aligned with sustainable development practices, since it can lead to the reduction of CO2 emission, waste management due to using industrial waste materials, and indeed preservation of natural resources (Verma, 2022).

Geopolymers are made through the process of polymerization of aluminosilicate material along with alkali as an activator (Farooq, 2021). There is a variety of different alternative industrial waste materials as precursors such as fly ash, ground granulated blast furnace slag, metakaolin, rice husk ash, to name a few of its components that include common activators, e.g. Sodium hydroxide (NaOH), sodium silicate (Na2SiO3), potassium silicate (K2SiO3), and potassium hydroxide (KOH) alkaline solutions (Akhtar et al., 2022).

1.2. Problem statement

Several works have been conducted about sustainable construction materials (CO2 mitigation) in the scientific literature, such as geopolymer concrete as an alternative to replace conventional concrete (Verma, 2022; Farooq, 2021; Almutairi, 2021). However, there are still some barriers hindering their utilization in this sector. One of the crucial barriers is considered lack of knowledge and low awareness of its application. The adoption of this geopolymer concrete is still limited even though its environmental and cost-competitive benefits are promising. Therefore, addressing the lack of sufficient knowledge and information about geopolymer concrete, this study aims to explore the current barriers to its acceptance and use as one of the sustainable building materials.

1.3. Research objective

The main objective of this study is to explore how the knowledge of professionals within the construction industry can influence the adoption of geopolymer concrete as a sustainable building material. In doing so, the current level of knowledge and awareness of construction professionals such as engineers, architects, and contractors will be identified. Besides, this study aims to examine the main factors contributing to the knowledge gap among Professionals.

1.4. Research question

The main research question (RQ), which is aligned with the objective of this study, is presented as follows:

"How does the knowledge gap among construction professionals influence the adoption of geopolymer concrete in the Dutch construction industry?"

For a depth analysis, the main RQ has been disaggregated in some of its elements and the result is the identification of three sub-questions.

1. What is the level of awareness and understanding of geopolymer concrete among professionals in the construction industry?
2. What prior conditions contribute to the knowledge gap regarding geopolymer concrete adoption?
3. To what extent do construction professionals' characteristics influence the knowledge regarding geopolymer concrete?

2. Literature Review

This section offers a comprehensive review of the literature on sustainable construction materials, particularly geopolymer concrete, and the barriers and challenges to the adoption of such materials. First, it provides some information about sustainable construction as a crucial concept, then geopolymer concrete as the specific sustainable building material. In addition, this section explores the barriers that hinder the adoption process, while addressing the lack of knowledge and awareness as the main factor. Besides, the theoretical framework which is in line with the objective of this study is explained.

2.1 Sustainable construction

There is an increasing trend in the construction sector towards sustainable construction, which is technically defined as practices to mitigate the adverse impacts of the given industry on the environment, natural resource depletion, and global warming issues (Ahn et al., 2013). Besides, sustainable construction not only focuses on economic profits, but also aims to concentrate on advantages for society and reducing harmful environmental impacts, waste management, and reuse. Striking a good balance between long-term environmental benefits and short-term profitability to attain a balanced system is important since it leads to having a direct effect on the overall success of the ongoing projects (Shen et al., 2010). Some elements could have an influence on the sustainability of construction projects and one of them is called "eco-design". This term is a modern version of its original "green design", where it takes ecological and environmentally sound design aspects into account (Baumann et al., 2002). Moreover, it is crucial to consider sustainability practices during all the construction stages from design to demolition and renovation. This is because the construction materials could be reused and recycled during deconstruction, contributing to environmental sustainability, and reducing the use of natural resources (Petzek e al., 2016). This approach aligns with the circular economy principle that could have a major role in the construction sector by moving toward zero-energy buildings, sustainability innovations, reuse, and reassembly of building materials from the beginning stages (Iyer-Raniga et al., 2020). Sustainable construction benefits the involved stakeholders as it facilitates the efficiency of projects along with waste management and GHG emission reduction. In other words, sustainable building practices should aim to minimize waste and pollution, select sustainable materials that can be reused and recycled, and implement water and energy-saving processes in construction projects (Amaral et al., 2020).

2.2 Geopolymer concrete as a sustainable building material

It has been a while since geopolymer concrete (GPC) started raising attention as a replacement material in the construction sector as it aligns well with sustainability practices in this industry. Moreover, the construction industry benefits in several aspects because of utilizing GPC in ongoing projects. For instance, compared to traditional concrete, GPC contributes to reducing carbon emissions, so that the issues related to global warming can be mitigated (Hassan et al., 2019). This feature is of great importance since the negative environmental impacts of construction activities should be addressed with urgent need. Furthermore, GPC takes advantage of recycled industrial waste materials, such as fly ash and ground granulated blast furnace slag. Thus, the need for extracting raw materials and waste generation afterward could be managed in a better way. This is also aligned with circular economy principles, which highlight reusing materials and waste management. It is also noteworthy that GPC has demonstrated life cycle cost saving, leading to making it a cost-competitive sustainable building product in the long run (Hassan et al., 2019). Consequently, GPC is considered a promising alternative construction material that could replace traditional concrete when it offers environmental and cost-efficient benefits, enhancing the process of transition toward sustainable building practices (Fig. 3)

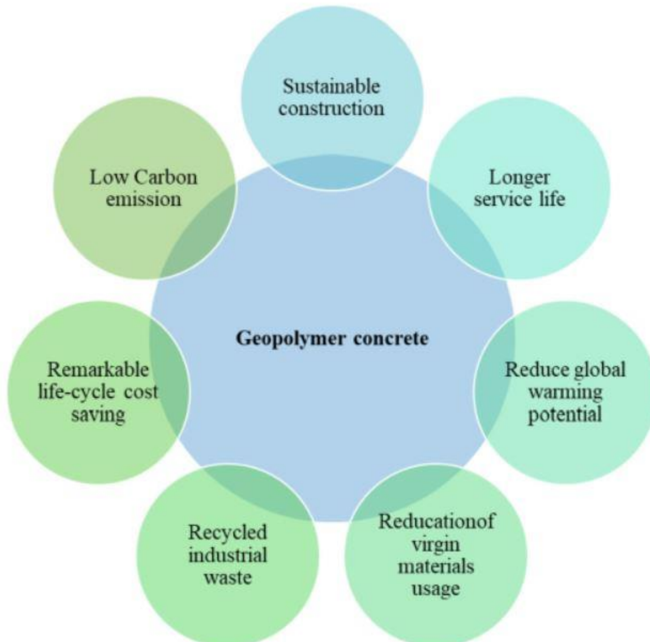

Fig. 3 Benefits of using GPC in sustainable construction (Hassan et al., 2019)

Another study compared the ecological footprint of GPC with conventional concrete and revealed the environmental benefits of this type of sustainable material (Akhtar et al., 2022). In this study, the ecological footprint (EF) of GPC made of fly ash was evaluated with three types of conventional concrete. It turned out that GPC was the material that had the lowest EF in comparison to all other conventional types of concrete (Akhtar et al., 2022). This can showcase the contribution of GPC to fostering sustainable construction practices. Furthermore, the paper highlighted the additional benefit of GPC in terms of its potential to be cost benefit when it comes to contrasting with conventional concretes (Fig. 4). Aktrar et al., also stated that this material could result in a reduction of carbon emission and sustainable waste disposal of fly ash, slag and other. Through mass production.

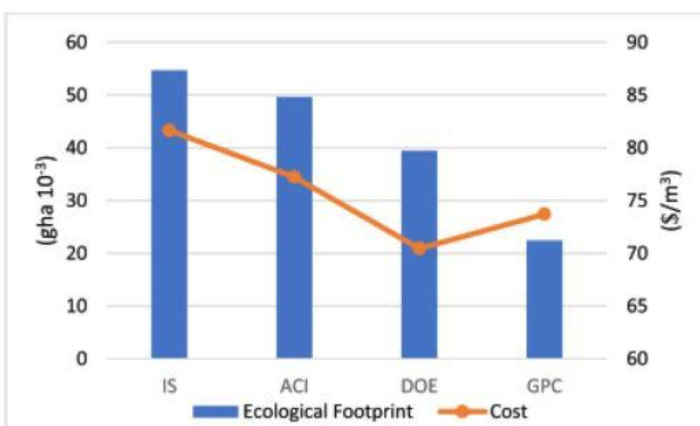

Fig. 4 EF and cost of GPC and conventional types of concrete

2.3 Barriers to implementing sustainable construction.

A study done by Tokbolat et al. about stakeholders' perspectives on the main barriers and drivers of sustainable construction adoption in Kazakhstan. They just used survey questionnaires to gather professional attitudes in the construction industry where they included architects, designers, engineers, consultants, managers, and builders. These stakeholders were good representatives of the group, because of their affinity with construction norms and standards, participation in the related projects, and the local context of the sector, which could identify which factors are most influential for sustainable construction in Kazakhstan (Tokbolat et al., 2020). According to their findings, environmental-related factors such as energy and resource efficiency were ranked as the highest drivers of sustainable construction. These factors were also followed by social sustainability elements to be considered among the most important drivers in comparison with economic drivers. However, the initial costs of sustainable building options along with a lack of awareness and knowledge and lack of promotion and incentives from the government (Tokbolat et al., 2020). It should be emphasized that such lack of awareness and knowledge on sustainable construction practices not only is the most crucial barrier to adopting them but also, could turn into a significant driver, resulting in engaging construction stakeholders (Tokbolat et al., 2020). In addition, they suggested that the result of this study could be implemented in other Central Asian countries since they have similarities in terms of their contextual and cultural aspects. While such a finding is in a broader scope, its emphasis on the role of awareness and knowledge among construction professionals aligns well with the focus of this research. Thus, making use of the insights from the findings serves as a source of information, highlighting its relevance and applicability to explore professional knowledge in the context of the Dutch construction sector.

2.4 Barriers hindering the adoption of sustainable building materials.

Incorporating sustainable building materials into architectural design and construction is becoming increasingly recognized. However, there are still some barriers hindering the widespread implementation of such materials. According to the study in Nigeria, Akadiri emphasized that there was a perception among construction professionals that sustainable materials tend to be more expensive and existed challenges of lacking enough information about them. He showcased that lack of access to information about such products led to an adverse impact on decision-making. This is because when they are not informed about the benefits of sustainable products, they prefer to follow the way of a "safe" solution where they choose conventional supplies over other sustainable alternatives (Akadiri, 2015). On the other hand, when those main stakeholders were aware of such material features, they adopted them through their construction projects. Another barrier is the perception of extra time needed to spend on sustainable materials adoption which might lead to delaying the construction projects with restricted deadlines (Akadiri, 2015). Having said that, he underpinned that there is a knowledge gap among those professional stakeholders which necessitates the need for professional training and development to cope with this gap. Therefore, Akadiri proposed some solutions such as initiatives from the government to raise information and training on sustainable materials as well as related policies and regulations to promote using such materials.

Ahmed et al. researched the barriers impeding the adoption of sustainable construction in Qatar and other countries in the building industry. They identified the five most important variables, including insufficient regulations and construction codes, lack of information and educational curricula to help with understanding green and sustainable practices, difficulties in attaining relevant skills, and lack of funding and investment (Ahmed et al., 2023). Their findings about the knowledge lacking were aligned with (Hwang et al., 2018) research where they implemented a similar study of implementing sustainable construction for small contractors in Singapore. Hwang et al. identified six barriers that hindered sustainable construction practices and categorized them into three major groups. They stated that "knowledge barriers", "financial barriers," and "management barriers" were crucial issues facing small contractors compared to larger ones. They also provided some solutions to cope with the current barriers, emphasizing the role of government through giving subsidies and encouraging demands for sustainable construction in public projects.

The construction industry is considered a complex system with its resistance to change nature (Vakola & Wilson, 2004). Such nature is showcased in a way that there are barriers when it comes to adopting sustainable construction. Petri et al., for instance, discussed these perceived barriers at three-dimensional levels of individual, organizational, and industry (Table 1). At the individual level, a lack of actionable knowledge about sustainable construction was factored in as the crucial barrier through industry consultation, where it was followed by uncertainty, because of the knowledge gap, and distrust in existing sources of information (Petri et al., 2014). At the organizational level, fragmented information, and lack of access to sustainability knowledge along with being skeptical about the cost-efficiency of such sustainable solutions were among the existing barriers. It is said that even at this level there was a strong relationship between the knowledge gap and the perceived barriers, emphasizing the need to address this issue in the construction industry. In the wider view of the industry level, there was an argument about the primary focus of government on regulation while such industry is struggling with engaging sustainable construction, stemming from the poor knowledge and education among its stakeholders (Petri et al., 2014). Addressing the given issue, Petri et al., proposed a solution called the Sustainable Construction Service Platform (SCRIPT), which highlighted its features such as mobile computing and social networking. The authors emphasized the importance of Information Communication Technology (ICT) in the construction industry, where a web-based model could contribute to spreading and managing knowledge within the given sector. The development of such platforms could play a role in integrating fragmented information about sustainable construction by providing access to dynamic and user-oriented content, resulting in fostering collaboration and knowledge distribution among key stakeholders (Petri et al., 2014).

Table 1 Perceived barriers to engagement with sustainable construction (Petri et al., 2014)

Individual perceived barriers	Context
Lack of knowledge	Knowledge about sustainable construction, including practices and principles; availability/accessibility; information overload
Uncertainty and scepticism	The necessity for, and effectiveness of sustainable construction practices (both industry stakeholders and end-users).
Distrust in information sources	Including consistency, validity, authority, and timeliness
Reliance on technology	Including new technologies for sustainability, and for information retrieval
Resistance to lifestyle change	Perceived threats include changes in living standards, inconvenience, cost
Organisational perceived barriers	**Context**
Lack of enabling initiatives	Information and knowledge sources are fragmented, diverse, unstructured, non-integrated
Lack of training	Including understanding the skills need; raising the demand for skills; understanding how to up-skill the workforce
Work overload and priority to expedite current tasks and activities	Including within tight financial margins
Lack of information/knowledge sharing	Including commercial imperative, costs, trust
Wider industry perceived barriers	**Context**
Lack of government action	To initiate and promote energy positive behavioural change
Government focus on regulation	In an industry which suffers from poor stakeholder education

2.5 Geopolymer Concrete and its components

Geopolymer concrete (GPC) is characterized by having high aluminosilicates (ASs) content and exhibits similar features to the cement family (Singh et al., 2015; Das et al., 2014). It requires alkaline medium to function properly since its composites stay unreactive in the presence of water (Wongsa et al., 2020). When they are placed in an alkaline binder, they create a 3-D polymeric structure with load-bearing capacity. GPC is considered as promising sustainable building material that could be highly utilized in construction in the future (Amran et al., 2020). GP composite is synthesized using alkaline sources of materials that are abundant in ASs. A significant number of AS is found in by-product waste materials such as fly ash (FA), slag, rice husk ash (RHA), red mud (RM), metakaolin (MK), and silica fume (SF). In the presence of alkaline medium, such raw materials experience the geopolymerization process. Consequently, this process results in achieving higher strength to a similar level compared to traditional cement composite (Farooq et al., 2021).

Fly ash (FA)

Fly ash (FA) is a by-product that is generated during the combustion of coal to produce energy in specific industries and power plants (Talakokula & Bhalla, 2016). It is considered as a replacement for traditional cement component, consisting of alumina ($Al2O3$) and silica ($SiO2$). FA plays an important role since its reaction with lime ($Ca(OH)2$) and water can produce components with similar cementitious characteristics. Therefore, this application makes it to be widely used in variety of mixtures, mortars, and concrete (Wongsa et al., 2020). Utilizing FA for the geopolymer concrete (GPC) as a supportive component enhances its durability properties. FA can act as a binder in the GPC application, where it produces AS gel ($AlNa12SiO5$) (Castel & Foster, 2015). Besides the durability, replacing the traditional cement (OPC) with FA in concrete leads to achieve higher strength and resistance to sulfate attack (Mantese & Amaral, 2017). Another important usage of FA in concrete is its environmental benefit impacts as it contributes to lowering the greenhouse gas emissions, water consumption, and energy usage. In addition, because of using this by-product it has a positive impact on optimizing the landfill space (Poudenx, 2008).

Ground granulated blast furnace slag (GGBFS)

Another industrial by-product is ground granulated blast furnace slag (GGBFS) that is obtained in the manufacturing process of iron and steel industry in blast furnace. This by-product is also well known for its effective use in the production of cement, mortar, and concrete (Suresh & Nagaraju, 2015). GGBFS can be used as an important substitute for traditional cement (OPC) by 35%-70% in the concrete mixture. Utilizing it in the GPC offers high value properties when it is finely grounded and used in combination with other materials. It consists of glass particles along with mono-silicates with similar structures of cement (OPC) clinker that can be dissolved in different mediums (Farooq et al., 2021). However, its irregular shape may affect the flow properties while it is mixed with other cementitious components. GGBFS is considered as a promising binder for GPC production as it enhances the mechanical properties, resistance to sulfate and alkali-silica reactions, void refinement, and heat generation (Nagajothi & Elavenil, 2020).

Red mud

Red mud (RA) is another by-product that is rich in alumina ($Al2O3$) content, obtained from the Bayer's process for refining bauxite to alumina (He et al., 2013). This by-product is featured by its highly alkaline nature which classified as toxic industrial waste. However, its application particularly in the cement industry has resulted in eco-friendly outcomes due to reuse practices. Therefore, by using red mud in GPC production, it provides sustainable yet economic way when it comes to disposing of hazardous wastes (Almutairi et al., 2021). Utilizing red mud in proper proportions is found to be effective in increasing the compressive strength and setting time of the concrete. Besides, addition of RM leads to providing more reactive silicone to the GPC which streamlines the process of geopolymerization (Kumar et al., 2021).

Rice husk ash (RHA)

Rice husk ash (RHA) is a side-product, mainly used as fuel for electricity generation, that is produced during the burning process of rice husk. RHA is known as an exceptional pozzolan that is suitable to be used in special concrete mixtures. This characteristic is because of its amorphous features and high silica content (He et al., 2013). Using RHA in the production of GPC can reduce temperature effects which takes place during cement hydration. In addition, it facilitates the workability of the concrete by increasing the setting time and decreasing the permeability to avoid the dangerous effect of ions. As a result, partial replacement of cement with RHA result in improving strength, durability, and resistance to sulfate attack of the concrete mixtures (He et al., 2013).

Silica fume (SF)

Silica fume (SF) is a by-product gathered during the manufacturing process of silicon and ferrosilicon alloy, utilizing a furnace and electricity. It is also characterized as micro silica or condensed silica fume, existing in a fine powder form with a 0.1 mm diameter (Yaseri et al., 2017). It consists of shapeless silicon dioxide and fine particles, making it highly reactive. In addition, because of its large surface area, it is featured as an effective pozzolan used in concrete. Therefore, SF is considered a supportive material for geopolymer concrete production. After SF is added to the concrete mixture, the reaction of silica with portlandite results in the development of calcium silicate, filling voids in the concrete. As a result, this process enhances the durability, water resistance, and strength of the concrete (Yaseri et al., 2017).

Metakaolin (MK)

Metakaolin (MK) is a mineral material rich in kaolinite and obtained from kaolin. Kaolin is utilized in different industries, such as ceramics, papers, rubber, and paints. It is also used in concrete production to develop the durability, strength, and performance of cementitious materials in concrete and mortars (Yaseri et al., 2017). MK is considered a suitable binder for GPC production, where the calcination process transforms kaolin into a reactive pozzolan. It consists of alumina silicate composites with semi-crystalline phases, such as quartz, mullite, and anatase. Images obtained from scanning electron microscope (SEM) reveal that MK has a plate-like structure, leading to enhancing the process of geopolymerization in GPC production (Yaseri et al., 2017).

2.6 Roadmap CO2

The Roadmap CO2 is part of the Concrete Agreement NL (BetonAkkoord) initiative introduced in the Netherlands on July 10th, 2018. This initiative was set up to achieve more sustainable solutions in the construction industry. Some of the main features of this initiative are reducing CO2 emissions, practicing a circular economy, and improving sustainability during the production and usage steps in the concrete sector. The Roadmap CO2 includes quantifiable targets and milestones to reduce CO2 emissions. It aims to facilitate the transition toward low-carbon solutions in the construction sector. Here are the targets of the Roadmap CO2 compared to 1990:

1. At least 30% CO_2 emission reduction by 2030.
2. The ambition is to attain a 49% reduction by the given time.
3. Reaching to a 100% reduction in 2050 (carbon-neutral).

The CO_2 emission was approximately 3.8 million tons in 2017; when 68% of the emission originated from concrete materials. It was followed by 21% from reinforcing steel, 8% from transportation, and 3% from demolition and reuse. As is shown in Fig. 5 from 2017 to 2030, a 1.25 million tons CO_2 reduction is needed to achieve the objectives of the Roadmap CO_2.

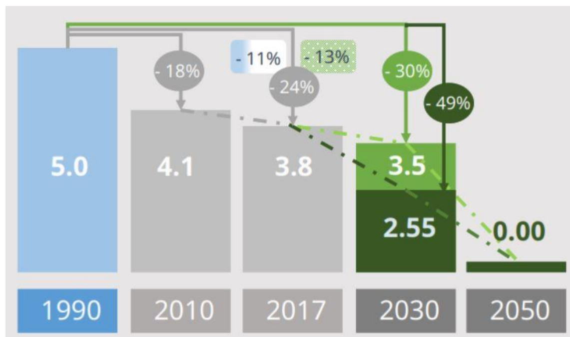

Fig. 5 Milestones for CO_2 emission reduction in the construction industry (Pieter van Ghent, 2021).

There are two scenarios for CO_2 reduction in the roadmap and each scenario is based on the availability of certain materials. A 60% reduction is assumed in scenario 1, where the shortage of available fly ash as a precursor is considered. In scenario 2 with a prediction of finishing blast furnace slag in 2030 a 50% reduction is predicted. However, both scenarios show higher targets when it comes to comparing them with the ambition of a 49% reduction in 2030. Fig. 6 illustrates the roadmap for CO_2 reduction from 1990 to 2050 along with two scenarios.

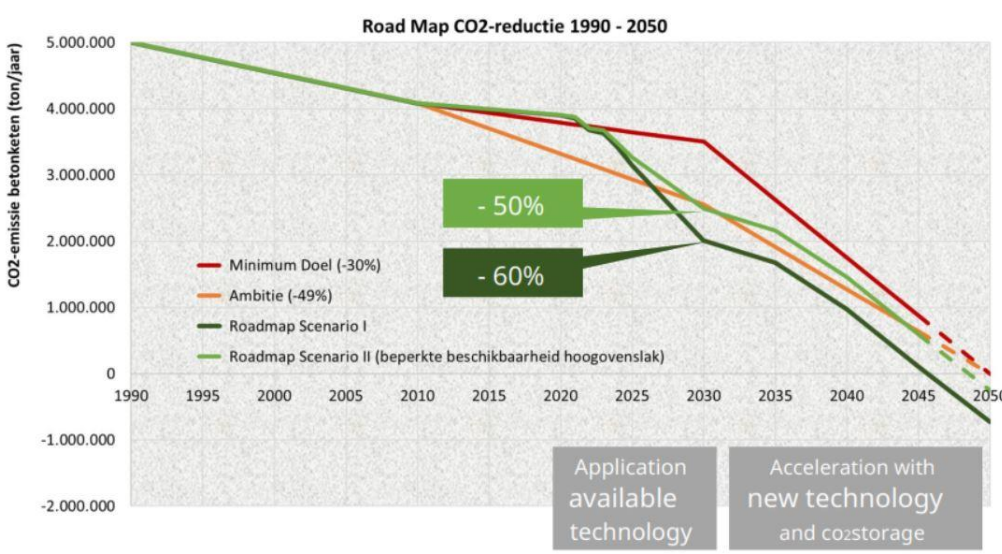

Fig. 6 Roadmap CO_2 reduction from 1990 to 2050 (Pieter van Ghent, 2021).

Reaching the reduction objectives, several strategies are identified in the roadmap. One of the strategies is enhancing energy efficiency in the concrete sector through reducing energy usage. The next strategy is utilizing different types of binders like geopolymer concrete with a lower carbon footprint. In addition, increasing the usage of recycled materials and practicing a circular economy leads to emission reduction. Another method is to invest in innovative technologies such as carbon capture storage (CCS) and low-carbon fuels. Conducting these strategies contributes to facilitating the CO2 emission reduction process.

In the last update, the concrete agreement started its final phase in 2024 when the initiative with collaboration with more than 250 involved parties since 2018 has set more ambitious goals. In the scale-up phase, the targets are even stricter for 2030 with at least a 70% reduction in CO2 emission compared to the levels in 1990. Other aspects to be factored in are becoming fully circular and prioritizing prevention and reuse. Moreover, the natural capital is supported by Concrete Sustainability Council (CSC) guidelines to preserve biodiversity. The scale-up phase also includes new standard development, and an emission-free transport roadmap while all parties will be informed about potential outcomes (Betonakkoord, 2023).

The CO2 emission reduction objectives set in the concrete agreement are achievable. However, this initiative requires collaboration among all stakeholders and involved parties, like construction companies, the government, suppliers, and research institutes, resulting in a successful application. In addition, most of the action plans are now feasible with current technological developments and financial incentives could be a barrier. It is noteworthy that accelerating the application could not be fully attainable unless an environment for sharing and transferring knowledge to all actors within the construction sector.

2.7 Theoretical Framework

Research has shown that the process of adopting innovation in any industry, in this case, the construction sector, is highly influenced by positive or negative perspectives about it, as specified by professional knowledge (Weerapperuma et al., 2022). According to Weerapperuma et al., the process of innovation adoption in the construction industry from individual perceptions is hindered by the following reasons. He stated “resistance to change behavior” as a reason for the lack of innovation adoption. Furthermore, he highlighted the “lack of knowledge and competencies” has a direct impact on the given reason related to resistance.

2.7.1 Diffusion of Innovation (DOI) Theory / Framework

The DOI framework is “the process by which an innovation (idea) is communicated through certain channels over time amongst the members of a social system” (Rogers, 2003, p. 5). This framework has also been widely used when it comes to technological innovations. Such a theoretical model can provide a better understanding of how knowledge about the given technology could be exchanged and disseminated within an organization, which makes it distinct from other models and frameworks (Greenhalgh et al., 2005). Therefore, taking geopolymer concrete as a technological innovation within the construction company, this framework can adequately address the knowledge-related issues about its adoption. There are four main elements in DOI theory, namely innovation, communication systems, time, and social systems (Rogers, 1983). The innovation itself is about an idea, product, or service that is perceived as something new when it comes to its usage. The next one is described as channels that are associated with the movement and sharing of knowledge and information. These communication systems are of great importance where better and well-organized systems result in faster diffusion of innovation (Ahmad Wani & Wajid Ali, 2015). According to Rogers, they are categorized into two groups mass media and interpersonal channels. Although mass media can contribute to a quicker distribution of information, he believed that interpersonal channels had a more influential impact in this way. This is because "diffusion is more like a social process which involves interpersonal communication relationships" (Rogers, 2003). Besides, time is indeed another factor that is defined as the pace of the adoption process through dispersing innovation into a society and different target users (Ahmad Wani & Wajid Ali, 2015). The social system is also a crucial element since the diffusion of innovation is not meaningful unless the social system accepts it. Then, it could be disseminated within the related system (Rogers, 2003).

Based on Roger's model the adoption process of innovation goes through five stages knowledge, persuasion, decision, implementation, and confirmation (Rogers, 2003). Fig. 5 shows the five stages in the innovative decision process. The knowledge stage is considered the initial stage where individuals become familiar with the given innovation. In this stage, they know about innovation through communication channels, where they begin to ask about what, how, and why questions regarding that innovation (Rogers, 2003). Therefore, such questions lead to a generation of three types of knowledge: awareness-knowledge, how-to-knowledge, and principles-knowledge. The awareness-knowledge is the first formation about the existence of innovation, helping to encourage individuals to explore more about other forms of knowledge. The second type deals with the knowledge of how to use that innovation (Sahin, 2006). According to Rogers, having an adequate how-to-knowledge type is essential since then there is a higher chance of adoption, particularly in terms of more complex innovations (Ahmad Wani & Wajid Ali, 2015). Consequently, the principle-knowledge is the last type that incorporates functioning principles where individuals could address the why and how questions about the innovation. Furthermore, besides knowing, an individual's perceptions are also important as they play a major role in adopting or rejecting the given innovation (Sahin, 2006).

Within the DOI, the knowledge that is attained during the first stage needs to be further explored and justified through the persuasion stage. This is because individuals might not immediately tend to adopt the innovation even though they already have access to the knowledge (Weerapperuma et al., 2022).

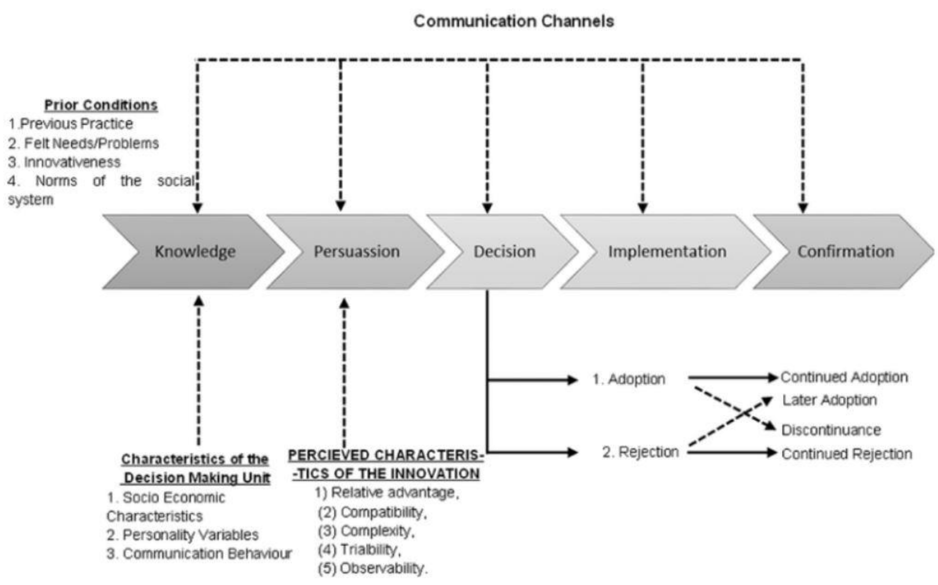

Fig. 7 Five-stage model in innovative-decision process (Rogers, 1983)

This study aims to utilize the DOI framework elements, which are related to addressing the main objective and research questions. Utilizing the elements of DOI in the knowledge stage provides a lens to investigate construction professionals' awareness regarding innovative materials like geopolymer concrete. This framework benefits this study since it can reveal how trends and updated information are communicated in the construction sector. Besides, its focus on knowledge gathering and how it influences the adoption of innovation offers a valuable basis for pinpointing the contributing factors. Therefore, the focus is on the following components:

Communication behaviors and socio-economic characteristics are incorporated since these factors will contribute to shaping professionals' attitudes and awareness, leading to a better insight into knowledge distribution and adoption of geopolymer concrete in the construction sector. Moreover, implementing prior experience, felt needs/problems, and norms of the social system will help with exploring contextual factors that play a role in the knowledge gap among construction professionals. In addition, while there is a focus on the knowledge stage this study will use the attributes of the persuasion stage, the relative advantage, compatibility, and complexity to explore how professional's knowledge can influence their willingness to adopt the geopolymer concrete.

3. Methodology

This section provides the research strategy and methodology for investigating the knowledge gap about the geopolymer concrete in the Dutch construction sector. It encompasses the research design, data collection steps, and data analysis techniques to address the objective and research sub-question of this study.

3.1 Research strategy

This main objective is to explore the knowledge gap about geopolymer concrete in the Dutch construction industry. This research aims to analyze the potential factors contributing to the insufficient knowledge about such innovative building materials. To achieve this goal, diffusion of innovation theory (DOI) was set as a theoretical model, and specific steps of this theory were utilized. Then, the elements of the first step of DOI, the knowledge step, served as a basis to address the objectives of this study. The research approach is mainly qualitative, using semi-structured questionnaires for interviews and literature review. The qualitative approach is selected because it provides a better understanding of professionals in the construction industry, who are involved in adoption of geopolymer concrete. A semi-structured interview gives the flexibility to identify different perspectives while focusing on the research questions and objective of the study. In addition, the literature review serves as a complementary source by providing relevant background information. For semi-structured interviews, a questionnaire was designed using DOI knowledge step components. The elements were three levels of knowledge forms, prior conditions to the innovation process, and the characteristics of the target unit. Therefore, the questionnaire contains questions created based on those three categories. The DOI theory helps identify the specific factors by analyzing the responses gathered from interviews.

3.2 Research unit

The research unit in this study is professionals in the construction sector in the Netherlands. At first, there was an effort to include professionals from different groups of contractors, engineers, managers, architects, suppliers, and consultants., who are involved in building projects. Considering a diverse group of target stakeholders within the construction sector aimed to gather a comprehensive insight into geopolymer concrete adoption. Specific criteria were selected to approach the target stakeholders for this study. The criteria for choosing construction professionals were based on their experience, position, and involvement in construction projects, particularly related to geopolymer concrete. The next step was to approach potential participants through their affiliation with construction projects, professional networks, and industry associations. After that, those who met the criteria could be invited to do the semi-structured interview. This approach provides a perspective on the specific context of the Dutch construction sector about adopting geopolymer concrete.

However, despite a great effort to approach the target group in various areas in the construction sector, there were significant challenges. Different construction companies involved in civil projects were approached initially through their contacts such as email and a phone call. Most companies did not respond to participate in this research although they were informed about the voluntary nature of the study and their contribution’s impact on enhancing innovation. Therefore, the strategy was changed to approach target individuals via their contact emails and LinkedIn profiles. This approach also included some issues. While many professionals accepted the connection request, they did not continue after initial contact. In addition, some of them showed a willingness to the study and asked for the questionnaire before conducting interviews. However, they did not go any further as no responses were taken from them afterward.

3.3 Analytical framework

The analytical framework is illustrated in Fig. 6 where it demonstrates the main steps that are going to be taken so that it leads to answering the research questions of this study.

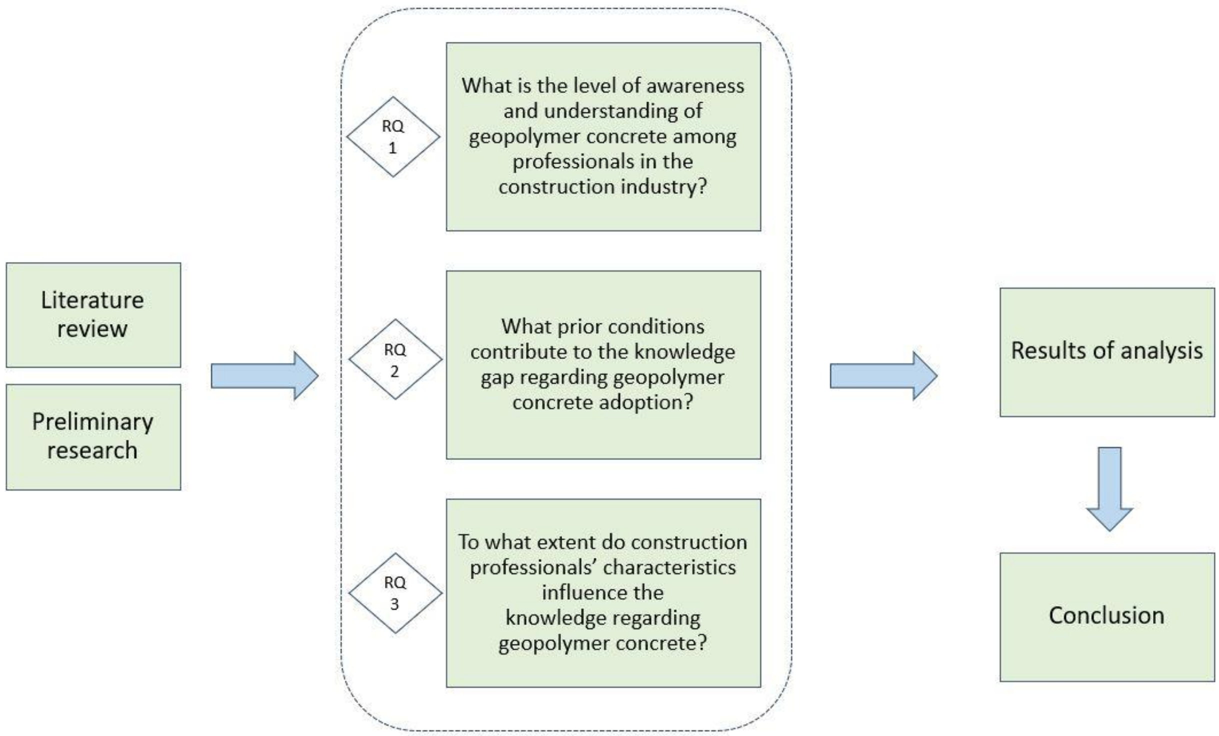

Fig. 8 Schematic diagram of analytical framework

3.4 Data collection

In this study, the data collection process was done using mainly the responses from semi-structured interviews. After that, a literature review was used to validate the proposed responses as much as possible. Conducting this step contributes to addressing the sub-questions of this study through qualitative research, leading to a deeper insight into construction professionals' awareness of the geopolymer concrete adoption in the Netherlands. The literature review in this study provides a solid foundation by gathering information about geopolymer concrete as a sustainable building material and obstacles to adopting such material. In doing so, different authentic sources including peer-reviewed papers, scientific journals, and conferences, to name a few, were utilized to synthesize information. Besides, this source helped with the process of interpreting the findings of the study.

Moreover, the semi-structured interviews were conducted with professionals in the construction industry, using open-ended questionnaires. The open-ended questions were designed to extract information from target participants on knowledge lacking and challenges related to geopolymer concrete. Implementing such an approach benefited this research since participants could express their ideas and information in their own words, resulting in a better understanding of their awareness level and potential barriers existing in the given case (Table 2).

Table 2 Methodology approach to answer sub-questions of the study

Research Sub-Questions	**Data/Information Required to Answer the Question**	**Sources of Data**	**Data Collection Methods**
RQ1: What is the level of awareness and understanding of geopolymer concrete among professionals in the construction industry?	- Level of awareness and understanding of geopolymer concrete - Perception of professionals toward geopolymer concrete	- Previous studies on geopolymer concrete - Interviews with construction professionals	-Semi-structured interviews -Literature review
RQ2: What prior conditions contribute to the knowledge gap regarding geopolymer concrete adoption?	- Prior conditions contributing to the knowledge gap - Perspectives of different target individuals	- Interviews with stakeholders representing different attitudes	-Semi-structured interviews -Document analysis
RQ3: To what extent do construction professionals' characteristics influence the knowledge regarding geopolymer concrete?	- Knowledge of stakeholders towards relative advantages, compatibility, and complexity of geopolymer concrete - Influence on willingness to adopt geopolymer concrete	- Previous research on innovation adoption theories - Interviews targeting individuals	-Semi-structured interviews -literature review

For addressing the first sub-question, semi-structured interviews with questionnaires helped with the current knowledge and awareness among target professionals about geopolymer concrete. Choosing target participants was according to the selection criteria such as their professional position, experience, and proficiency related to sustainable building materials and their affinity with geopolymer concrete. Besides, efforts were made to engage with diverse representatives who were willing to participate openly. Therefore, this could pinpoint to what extent the hypothesis of lacking knowledge among construction professionals exists. Additionally, a comprehensive study of the literature review resulted in completing the information data gathered through the interviews.

Going to the second sub-question, data collection through the open-ended questionnaires was designed to highlight the factors that could contribute to the knowledge gap within the construction sector. Using elements of DOI regarding prior conditions provided a better understanding of their perspectives and potential experience toward geopolymer concrete adoption in the construction sector. Consequently, delving into possible obstacles hindering the adequate distribution of knowledge and information could enhance the rate of adopting the given innovation.

The third sub-question aimed to showcase how the characteristics of the target unit of individuals about geopolymer concrete could influence their tendency toward its adoption in building projects. Then, the perspectives of the participants were explored by conducting semi-structured questionnaires. This process involved gathering their attitudes about features of socio-economic characteristics, communication behaviors, and personality variables.

Therefore, implementing such data collection provided a holistic approach to exploring the research sub-questions of this study and facilitated the data analysis. In addition, gathering information about the knowledge and perception of target individuals shaped the deeper insight toward their attitudes, information, and challenges for geopolymer concrete adoption.

3.5 Selection of interviewees

As mentioned, there was an initial challenge in finding participants from the target individuals for this study. Finally, some construction professionals, who are highly knowledgeable about sustainability issues and geopolymer concrete accepted to participate in this research. After approaching them, they suggested reaching out to their colleagues and network to gather their attitudes about the objectives of this study. Besides, the next participants were among their network community and approached them through LinkedIn and email contact. Although they might not be a representative knowledge sample for all construction professionals, they provided a valuable source of information by sharing their viewpoints during the interviews. Their high level of expertise and awareness shed light on challenges within the construction industry regarding innovative building materials.

Participants met the main criteria to be chosen as potential individuals since they have relevant experience, knowledge, and affinity with innovative building materials like geopolymer concrete. They also demonstrated to have hands-on experience by running ongoing projects within the construction sector. A list of all participants with their professional information is shown in Table 3.

Eleven semi-structured interviews were conducted about innovative building materials through the online Teams platform. Each interview session lasted around 45 minutes to one hour to gather the viewpoints of each participant. After each session was recorded, it was transcribed right after the end to ensure covering any information during the interviews. Table 3 shows the participant codes, their level of experience and education, and their role for each participant in this research.

Table 3 List of participants with their role, education, and experience information

Participant Code	Role / Job Title	Experience / Education	Areas of Experience
P01	Concrete technologist, Owner of independent consultancy	Master's Civil Engineering, PhD in Robustness of Self-Compacting Concrete	Concrete technology, consultancy, self-compacting concrete
P02	Sustainable building consultant	Prefab concrete, insulation materials, and standards development	Introducing new products, plant organization, sustainability consultant
P03	knowledge disseminator in concrete for new materials, Inspirator	40+ years in the construction industry, involved in writing recommendations and guides for new materials, knowledge dissemination	Designing concrete structures, knowledge dissemination, new materials application
P04	Consulting Engineer and Associate Partner	BSc in Engineering, several post-academic studies, lecturer, arbitrator for construction disputes	Consulting engineering, lecturing, arbitration, construction disputes
P05	Concrete specialist	10 years in the construction industry, MSc from TU Delft	Traditional concrete, geopolymer concrete
P06	Professional engineer with a concrete affinity	Couple of years in the concrete sector, background in engineering	Concrete, small company startups and scale-up the business
P07	Geopolymer concrete specialist	+40 years in the concrete industry	Geopolymer concrete, Concrete and cement technology
P08	Project manager	25+ years in the civil industry, concrete expert	Project management, civil industry, concrete
P09	Concrete specialist and advisor	40+ years in the concrete and cement industry, degree in Civil Engineering, 12.5 years at the Concrete Society	Cement and concrete technology education, civil engineering
P10	Marketing advisor in concrete company	Experience in technical marketing and statistics	Concrete, technical marketing, statistics
P11	Technical Manager	30 years in the construction industry, PhD in Concrete Science, educated as a Structural Engineer	Research, consultancy, asset management, concrete industry, education, certification

3.6 Data analysis

Collected data and information from two sources of literature review and semi-structured interviews were analyzed in this study. This process delved into understanding the findings to address the research sub-questions efficiently.

The information attained during semi-structured interviews was analyzed through qualitative analysis. After collecting participants' responses through semi-structured interviews, the findings were interpreted to gain insight into attitudes toward geopolymer concrete adoption. Therefore, the main purpose of such semi-structured interviews was to extract information from the participants' answers to the tailored questions. After collecting the findings, the next process was to find similar themes from the responses. In this way, by comparing the results, such qualitative analysis could lead to attaining some patterns to address the research sub-question of this study. This also contributed to the validation process of the findings when it comes to interpretation. The data analysis from open-ended questions made it clear in terms of the professional's awareness and factors impeding the knowledge distribution regarding geopolymer concrete in the construction sector.

Then, the literature review was utilized to incorporate the systematic exploration of existing academic papers. It was obtained from authentic databases such as Scopus, and ScienceDirect, to name a few. Several keywords were used to find the papers considered to match the objective, such as sustainable construction, geopolymer concrete, barriers to adoption, professional knowledge, and a combination of them. Then a process of quick scanning was conducted. In this way, it started with going through the abstracts and results of the given papers and tried to narrow them down to those that were in line with the context of the study. After that, deeper reading was conducted on the papers that were among the most suitable regarding the relevance to the aims and research objective regarding knowledge lacking, sustainable building materials, and geopolymer concrete benefits and features. Such analysis contributed to gathering scientific information about the current knowledge and challenges in adopting geopolymer concrete in the construction sector.

Besides, some measures were taken to ensure the validity of the findings and results of this study. In doing so, the semi-structured questionnaire that was designed based on the DOI framework was sent to supervisors to check and get approval. Therefore, this process helped to revise and examine the structure before sending it to participants to design a questionnaire to address the research question and objective. In addition, after collecting the responses, the validity of the interviews was determined by utilizing a literature review, enhancing the credibility of the results.

3.7 Ethical considerations

According to the University of Twente ethics committee, research that is involved in gathering data from human beings should be submitted for ethical assessment before it is conducted. Therefore, the consent form was sent to each participant before the process started, so they could read and sign it back. Moreover, the participants will be notified about the context and purpose of the study and their right to withdraw at any time without any consequences. In addition, it is important to make sure that anonymity and other relevant information will be confidential in case of their request to do so.

4. Findings

In this chapter, the research findings of this study are presented. Each participant's response was gathered from the semi-structured interviews and all results were collected from answering the questions. The data findings aim to answer the sub-questions and the main research question. For each sub-question, several questions in the questionnaire were designed where related elements of knowledge step in DOI theory were applied (Appendix ll). The demographic details of the interviewees are presented in Chapter 3. This chapter is divided into three parts and each part answers the questions within the relevant sub-question category. It starts with the findings for sub-question one to show different knowledge form levels. Then, it continues to explore the prior conditions contributing to the knowledge gap about geopolymer concrete. Finally, it presents the answers to find how the target individuals' characteristics could influence their knowledge about innovative materials in the construction sector.

4.1 What is the level of awareness and understanding of geopolymer concrete among professionals in the construction industry?

This part presents answers to the questions to address the research sub-question one about the level of construction professionals' knowledge about geopolymer concrete. It includes three questions designed based on three knowledge forms. Three knowledge forms based on the DOI theoretical framework are awareness-knowledge, how-to-knowledge, and principle-knowledge, respectively. Therefore, the first three questions aim to discover those knowledge forms in the same order mentioned above. For the first question, the participants were asked about their familiarity with geopolymer concrete to explore the awareness-knowledge form. The next level, the how-to-knowledge, was examined through the participants' affinity with different types of binders used for geopolymer concrete. After that, the principle-knowledge form about this innovative building material was collected by asking about the advantages and disadvantages of geopolymer concrete over conventional concrete. It is worthwhile mentioning that efforts were made to present participants' responses qualitatively. This approach resulted in a better display of their knowledge and awareness about geopolymer concrete.

Awareness-knowledge

Participants first responded to what extent they were familiar with geopolymer concrete as an alternative building material. They mentioned different aspects regarding geopolymer concrete application. Interviewees highlighted its historical use in multiple countries, where it was initiated, and how it was developed. Then explained it gained interest particularly because of sustainability issues. They provided their experience with geopolymer concrete applications and ongoing projects. It demonstrates their practical knowledge when emphasizing pilot projects in real life. They showed awareness of its environmental benefits such as CO2 emission reduction and specific properties. In addition, they noted challenges regarding its application, including regulations, availability of materials, and need for research. Their qualitative responses regarding awareness-knowledge of geopolymer concrete are illustrated in the table below.

Table 4 Participants' main comments regarding awareness-knowledge form

Participant	Awareness-knowledge
P01	Alkali-activated materials, often referred to as geopolymers, are mentioned as an alternative binder system in concrete. Organizations like Betonakkoord promote geopolymers as a sustainable alternative, with many pilot tests in the Netherlands. Work experience with geopolymers based on copper slag.
P02	Geopolymer concrete has historical use in Egypt, Russia, and Belgium. Modern geopolymer concrete replaces cement with geopolymer binders and uses recycled aggregates. Successful projects like Echo Village and a bicycle bridge in Wageningen helped overcome initial skepticism. The main challenge is the lack of standardization, but tests show it performs as well as traditional concrete.
P03	Geopolymer concrete has been used in Australia for a long time and gained attention in Dutch construction over the last 10 years due to its sustainability. It reduces CO2 emissions by using blast furnace slag instead of Portland cement. Experimental use includes pavements and small infrastructure. Many unknowns remain, requiring ongoing research.
P04	Studied geopolymer concrete technology and assisted precast companies with its use. Engineered a 400 m^2 industrial slab using GPC and is a member of the CROW committee for structural GPC.
P05	Geopolymer concrete was introduced before WWII in the Soviet Union and later in Australia, the US, and the UK. It re-emerged in the Netherlands around 2015 due to sustainability needs. Uses no cement but activates slag and fly ash with an alkaline solution. The industry is conservative, and new materials take time to implement. Researchers are working on new activators to improve environmental impact.
P06	Geopolymer concrete is distributed via licenses to producers. Shares similar physical characteristics with traditional concrete but may not comply with regulations. Offers benefits such as high compressive strength, good adhesion with steel reinforcement, and improved resistance properties.
P07	Referred to the historical usage of geopolymer concrete and the culture of the concrete industry. Providing extensive knowledge about its usage and application.
P08	Geopolymer concrete does not use Portland clinker and performs equivalently to traditional concrete. It does not heat up during hardening and shows higher values for shrink and creep. Reduces CO2 by 50%. Not considered concrete under Eurocode due to the absence of a hydration process. Heat and chemical resistant, no ASR.
P09	Highlighted in the CO2 roadmap, expected to account for 8-9% of all concrete production. Uses similar precursors to Portland cement, like blast furnace slag and fly ash, which are already heavily utilized. Potential future challenge with fly ash availability due to changes in electricity production.
P10	Geopolymer concrete, also called alkaline-activated concrete, has historical use in the Soviet Union and Australia. Gaining attention due to sustainability. Hardens through a hydraulic reaction forming a CNASH gel. Positive mechanical properties compared to traditional concrete. Discussed in a knowledge document for Betonhuis members.
P11	Geopolymer concrete replaces the cement binder with an alkali activator. It is not the same as concrete defined by standards. A geopolymer concrete with a high CO2 profile is still not sustainable. Must have a low environmental impact and meet performance expectations.

How-to-knowledge

After exploring the participants' familiarity with geopolymer concrete, they were asked about different binders they could choose for a real project. They demonstrated high expertise in geopolymer concrete by providing a broad range of common and emerging binders. Interviewees mentioned blast furnace slag and fly ash as two common binders that are industrial by-products for making geopolymer concrete. Some participants also referred to alternative binders that are less common but promising such as steel slag, copper slag, and calcined clay. These alternatives could address the availability issues of precursors in the future. Industry practices are another consideration highlighted through responses. The categorization and standardization of different types of binders are needed to facilitate geopolymer concrete usage. Their qualitative responses regarding how-to-knowledge of geopolymer concrete are illustrated in the table below.

Table 5 Participants' main comments regarding how-to-knowledge form

Participant	How-to-knowledge
P01	Ground granulated blast furnace slag is used as the main precursor in geopolymer concrete. However, all available ground granulated blast furnace slag is already used as a partial replacement in commercial cement. Another precursor often used is fly ash or calcined clay, but these require a high dosage of activators, often resulting in a higher carbon footprint than cement. More promising types of precursors are steel slag, copper slag, or lead slag. The valorization of such currently not used resources would lower the global carbon footprint. Fundamental research into this topic is ongoing.
P02	The binder is typically sourced from industrial by-products like slag and fly ash. These materials are from electricity plants and steel production, often obtained at no cost. The process of activating these materials to serve as binders is proprietary, with information available on the SCAPE website, associated with SCAPE Technology. This indicates that slag and fly ash are commonly used as binders in geopolymer concrete, with the activation process being key.
P03	Mainly for projects, the construction company doesn't ask for binders; they just want concrete. Companies like SCAPE produce geopolymer concrete, and producers in the Netherlands can obtain it under license. Different types of geopolymer concrete exist, similar to variations in Portland cement types (e.g., Type 1, Type 2, Type 3). There's a need for categorization and standardization of geopolymer concrete types to facilitate usage and understanding.
P04	Both the precursor material (binders) and the alkali activators can be varied. Possible precursors are blast furnace slag, fly ash, calcined clay, and volcanic ash. Precursors can also be blended. Alkali activators can be sodium or potassium sulphates, hydroxides, or silica hydroxides.
P05	Geopolymer concrete uses binders such as slag and fly ash. Traditional cement is replaced with these materials. They are activated by an alkaline solution instead of cement. Common activators include water glass and sodium hydroxide. Researchers are also exploring new activators to improve sustainability.
P06	The main binder used is blast furnace slag, combined with other ashes. Research and experience have been focused on this specific binder, making it the primary choice. Regulations play a significant role in binder selection, with materials needing to comply

	with concrete regulations. Other potential binders include clay and additional ashes, but regulations for these materials are more challenging. Pavement projects are often used as a testing ground for introducing new binders due to fewer regulatory constraints.
P07	Mineral precursors such as Ground Granulated blast furnace slag, and fly ash, and activators such as liquid Sodium Silicate. But there are many more precursors and activators like 64 different combinations, each with various behaviors such as setting times.
P08	Known conventional binders include furnace slag and fly ash. Companies like E-Crete by the Zeobond group and SCAPE provide them.
P09	Currently, all binders used in projects are cement-based, such as fly ash and slag. However, there are upcoming developments expected within one or two years, like a new binder based on Portland cement with modifications to reduce CO2 emissions. It's crucial to stay informed about these developments for future projects.
P10	Refers to a variety of binders like furnace blast slag, fly ash, bio-based binders, and mentions their company Betonhuis specializes in such binders.
P11	Mostly a combination of fly ash and blast furnace slag. In some cases, a hybrid (partly cement-based) system is used.

Principle-knowledge

After providing answers to different binder applications, participants were asked about the advantages and disadvantages of geopolymer concrete compared to traditional concrete. This part was designed to explore their knowledge about principles as a third knowledge form based on the DOI theory. The major advantages of geopolymer concrete are environmental and technical performance benefits. Geopolymer concrete can reduce CO2 emissions by 50 to 80% and promotes waste reduction and circularity principles. It is more resistant to acid and chemical attacks and performs better in high-temperature environments with comparable compressive strength. Participants also referred to the disadvantages of using geopolymer concrete. The initial price of geopolymer concrete is generally higher, as it costs €185/m3 compared to €125/m3 for traditional concrete. Its workability and handling are other issues as it requires more strict safety rules. Therefore, knowledgeable personnel, who are familiar with its properties and handling processes, are needed. Their qualitative responses regarding the principle-knowledge of geopolymer concrete are illustrated in the table below.

Table 6 Participants' main comments regarding principle-knowledge form

Participant	Principle-knowledge
P01	Advantages: Unlocks currently unused resources; new material insights; specific technical benefits (e.g., acid resistance). Disadvantages: Higher material costs; many precursors are fully used in traditional concrete; higher overall carbon footprint due to activators; uncertainty about long-term behavior; lack of regulations and standardization; some properties (e.g., carbonation resistance) are inferior.
P02	Advantages: Similar strength to traditional concrete; more resistant to liquids and acids; better bending strength; significantly lower environmental impact (reduces CO2 emissions by 70%). Disadvantages: Lack of standardization; cement industry's resistance due to economic interests; ongoing innovation and standardization needed. Emphasizes the importance of considering lifecycle and environmental impact.
P03	Advantages: Main advantage is sustainability (no CO2 emissions); contributes to Paris Agreement goals; similar behavior to traditional concrete. Disadvantages: Differences in shrinkage mechanisms and reinforcement; requires more attention during execution; more research needed.
P04	Advantages: Lower CO2 impact; more resistant to chemical attack. Disadvantages: Alkali activators can be unsafe to work with; workability is more complicated.
P05	Advantages: Lower CO2 emissions; potential use of waste materials; high acid and chemical resistance. Disadvantages: Unknown long-term properties; high alkaline level requires strict safety measures; higher creep and shrinkage.
P06	Advantages: Significantly lower CO2 emissions (up to 60-70% reduction); can utilize a wider range of minerals, offering flexibility.
P07	Advantages: You do not have to invest € 200 Million for an OPC plant but can produce it in a garage. The CO2 reduction is significant, and reductions are between 50 to 80%. Tolerant to waste materials such as slags. Heat resistance. Disadvantages: Cost is still higher than ordinary concrete. Special care with liquid activator due to high P. Knowledgeable people needed. Regulations since standard concrete is prescriptive
P08	Advantages: Cold fusion product (external temperature has no impact); CO2 and MKI reduction; heat and chemical resistance. Disadvantages: Higher shrinkage and creep; harder to manage workability; higher cost (€185/m3 compared to €125/m3 for traditional concrete).
P09	Advantages and disadvantages vary depending on binders and mechanisms. Key properties (compressive strength, tensile strength, modulus of elasticity, shrinkage, creep, fatigue) need detailed investigation. Emphasizes the need for thorough study of these properties for specific use cases (e.g., columns, bricks, walls).
P10	Advantages: Low to very high compressive strengths; potentially better chemical attack and fire resistance due to fewer calcium compounds. Disadvantages: Lower modulus of elasticity; shrinkage may be higher; properties can lag behind expected values over time; method of post-treatment is important; requires additional research for reuse of recycled GPC to prevent alkali-silica reaction.

P11	Advantages: Low carbon emission; high circularity if secondary materials are used as binders. Disadvantages: Lack of standards to prove performance requirements; existing test standards for ordinary concrete may not be usable; limited experience and unknown long-term behavior make asset owners cautious.

According to the responses, some key trends regarding the knowledge of geopolymer concrete and its application are revealed. Participants demonstrated a solid awareness of its historical context and environmental benefits that initiated its usage globally. They showcased their familiarity with barriers hindering the adoption of new materials like geopolymer concrete. Obstacles such as regulation and standards, and availability of materials were constantly mentioned through the interviews. The key lesson learned is that despite the technical and environmental benefits of this new material there are still concerns about its practical implementation. Addressing these concerns about the regulatory frameworks and potential higher costs is needed to enhance its acceptance in the construction industry. Therefore, more research and development should be done in policies and standardization to overcome those issues.

4.2 What prior conditions contribute to the knowledge gap regarding geopolymer concrete adoption?

In part two, prior conditions according to the DOI theory are investigated. The designed questions aim to explore which prior conditions could contribute to the insufficient knowledge about geopolymer concrete in the construction sector. In this way, the research sub-question two is addressed by gathering responses from interviewees. The next question, question four, aims to discover whether previous experience might be the potential factor when participants were also asked about their experience with this innovative material. Then, question five asks about the challenges in the construction sector regarding geopolymer concrete, referring to the “felt needs/problems” element of the DOI theory. Another DOI component is innovativeness, which is asked in question six where participants share their viewpoints about willingness toward innovative materials. Next, participants responded to question seven about the common attitudes within the construction industry about geopolymer concrete. This question was designed to address the norms of the social system based on the DOI theory, where the construction sector is considered a social system. During the semi-structured interviews, participants provided valuable insights by sharing their attitudes about which factor could impact the knowledge about innovative solutions like geopolymer concrete.

Previous experience

Previous experience with using sustainable building materials can play an important role in influencing their adoption in the future. Participants provided real examples and evidence to showcase the significance of this prior element based on the DOI framework.

They highlighted the positive impact of successful projects on gaining knowledge and learning. Conducting pilot projects provides hands-on experience. Such projects along with ongoing monitoring and regular testing by organizations, where long-term performance data is available, result in overcoming skepticism toward these materials. As a result of the completion of more projects, its adoption and acceptance increase.

P01: “A project in which a geopolymer based on copper slag was used for a structural concrete application. It was not adopted on a big scale because of its limited carbonation resistance. However, our experience was valuable and helped us to obtain more scientific knowledge”.
P04: “Having hands-on experience is beneficial in gaining knowledge. Pilot projects are important to learn. However, GPC is not the solution for all concrete in my opinion. But it can be useful for several user cases”.
P11: “Our company in collaboration with TNO and BouwCirculair is currently assessing ten structural projects with geopolymer concrete. The information gathered through the evaluation process could provide a tangible source for defining a new standard for geopolymer concrete”.

Having real experience with new materials like geopolymer concrete is important where the benefits of their application are observable. Over the past two to five years, there has been an increase in gaining practical experience among clients and stakeholders. They have started to be confident with geopolymer concrete.

P03: “An example of the quick adoption of self-compacting concrete from Japan, suggesting that visible benefits for production processes can positively influence their adoption”.

On the other hand, limited experience with new materials is a challenging issue. The current knowledge and experience are based on conventional materials. The challenge part is shifting established knowledge and practices. It requires the professionals to learn more about innovative materials. Another challenge is integrating such new materials into building codes and standards and related regulations. The Dutch and European building industries are mostly based on their experience with cement-based concrete, particularly Portland cement. New innovative building materials lack sufficient data when it comes to comparison. Therefore, more testing and experimentation are recommended for gathering long-term performance data.

P07: “An example of ground calcium carbonate limestone as a cement replacement. It started in 1999 when there was zero market for this material, and how market acceptance would increase over time. Despite initial resistance, it eventually became accepted by the market. However, there is a lack of recognized standards for geopolymer concrete. This makes it more resistant to adoption”.
P08: “The asset managers responsible for decision-making have little experience with geopolymer concrete. This could affect the adoption of innovative materials in the future”.

In addition, previous failure experience with new materials could cause cautious approaches to their adoption. “P09” had another viewpoint about the experience with new materials. He brought up an example of a large train project involving green concrete, followed by chemical and acid attacks from exposure to plants and moss. Such experience made the Dutch contractors cautious about using innovative materials because of costly consequences. It is suggested that experimentation with such materials be conducted in smaller projects to mitigate the potential risks.

Felt needs/challenges.

Participants referred to needs in the Dutch construction industry regarding geopolymer concrete. They highlighted that geopolymer concrete can mitigate CO_2 emissions, the main environmental challenge of the construction industry. It also shows better performance with more efficiency and durability properties.

P07: "It can reduce the environmental impact of the construction industry by lowering CO_2 emissions. It could enhance material efficiency as you can do more with fewer materials".

Geopolymer concrete shows higher durability characteristics compared to traditional concrete and provides better performance in the long term. Geopolymer concrete could contribute to sustainability goals set by the public and private sectors. Geopolymer concrete could help construction companies show their commitment to mitigate their environmental impact. The market for sustainable concrete like GPC is small and is about 5% or less. However, there is a significant potential for growth and several challenges to be addressed such as regulations, market acceptance and education, and R&D for new materials.

Interviewees referred to the big challenge of the construction industry in sustainability. If concrete is part of a project and there is a strict sustainability requirement, geopolymer concrete can help to fulfill this requirement. A recent example is the procurement of two bridges in Dongen. There is a requirement for a low environmental impact (MKI). The contractor has therefore asked if it is possible to use geopolymer concrete. Dongen is prepared to use this innovation in this project. Geopolymer can improve the resistance against acids of concrete in specific applications. It might also be cost-effective when waste streams from processing household waste can be used as a precursor.

P08: "Geopolymer concrete could provide durable solutions for civil structures renovation and maintenance. (V&R opgave civil structures)"

Regarding challenges, participants highlighted current regulations and standards do not cover new materials, resulting in uncertainties. There are also concerns about the availability and cost of new materials. One challenge is the availability of materials. For instance, the blast furnace slag might be decreasing due to changes in the steel industry production. There is competition for blast furnace slag between the cement and geopolymer concrete industry. Another challenge is the lack of standards, codes, and sufficient experimentation for geopolymer concrete. The long-term performance of concrete for properties like fatigue and shear force including uncertainties. Existed European regulations do not fully cover internal forces for concrete design and might cause uncertainties in structural performance. The behavior of geopolymer concrete particularly in exposure to carbonation and chloride migration is still unclear.

P05: "It requires understanding these interactions to ensure the durability and reliability of geopolymer concrete in actual applications".

The cost is another important factor. Geopolymer concrete is normally more expensive than traditional concrete. CO2 reduction should be prioritized over price to encourage the adoption.

P09: “Although new types of concrete or binders have some benefits, there would be resistance if they are costly”.

Scaling up production could reduce the price difference between geopolymer and conventional concrete. The construction industry is price-driven and usually prioritizes building materials with lower prices. Funding from the government, however; for testing and experimentation could encourage the adoption of innovative and new materials.

Innovativeness

Innovativeness is another prior element of the DOI theory, explored in this study. This element was investigated when interviewees answered whether there is a willingness toward innovative building materials like geopolymer concrete. All the participants responded positively to this question and provided reasons to support their attitudes. Several participants stated that environmental concerns and sustainability initiate a willingness toward alternative materials. These concerns about reducing CO2 emissions require companies and organizations to consider new materials.

P02: “The shift in attitudes associated with climate change issues. Nowadays, decision-makers are more willing to explore innovative materials as alternatives to conventional methods”.
P03: “One of the concerns is the high carbon footprint of Portland cement which initiates interest in exploring alternatives. The precast industry, for instance, utilizes Type 2 cement, the most prevalent type, but may consider alternative materials for specific circumstances”.
P07: “Yes, there is a willingness. It is mainly because of the CO2 emissions reduction”.

In addition, there has been a shift in attitudes during recent years. The demand for sustainable building materials is increasing, showcasing more interest in their application. As a result, more clients and contractors search for geopolymer concrete instead of using traditional concrete in their projects.

P04: “The interest in using low-carbon concrete is increasing. I know several clients and contractors are looking into the possibilities of GPC”.
P05: “While there is no concrete proof, there has been a noticeable shift in attitude. A few years ago, geopolymer concrete was seen negatively, but now some clients are requesting its use”.

However, the perception of potential risks and initial costs makes its adoption with caution. Geopolymer concrete price is supposed to be more expensive, but the total project cost should be considered. Another challenge is that contractors, producers, etc. should ensure the durability and reliability of structures with new materials. Even though concrete producers are eager to adopt these new materials, the cement producers are not that much. However, changes can be initiated by a small group as it takes 9 to 15% of enthusiastic people to make it happen. It is also essential to have suppliers with sufficient knowledge about precursors, activators, and on-site support.

P11: “Asset owners, clients, and suppliers are more than willing to participate. If all of them are willing to participate in an innovation and the risk. Even some contractors are now willing if it is clear how the risks are dealt with”.

Norms /common attitudes of the social system

Regarding the norms within the construction industry, as a social system in this study, participants responded about common attitudes toward innovations such as geopolymer concrete. Their responses showed how they could influence the knowledge around such building materials.

There was a recurring theme throughout the interviewees’ responses about the conservative nature of the construction sector. They referred to its preference to stick to familiar materials and resistance to change mainly because of risks and cost implications. Despite enthusiasm about implementing innovations, the first application of new innovative material is an investment. Not every company has the resources to make such an investment as the profit margins in the Dutch construction industry are generally low.

P01: “Too little money is available for Research and Development. And clients are not always willing to accept potential risks in pilot projects”.
P02: “The construction industry is quite conservative because different stakeholders are involved”.
P08: “The construction company is pretty much reserved. This is mostly because the asset managers have little knowledge about GPC, so they rather go with conventional materials”.
P09: “The construction sector is reluctant to utilize new materials and tends to stick with conventional materials. This is mostly associated with reducing the risks due to safety issues and ensuring structural stability”.

It prefers to stick with familiar materials and is more cautious about new materials. The cost of the materials has a huge role as often it favors options that comply with standards yet are cost-effective. Despite an interest in sustainability, companies and engineers have issues about initial costs and risks associated with new materials. Besides, the conservative nature of this sector gets in the way of gaining knowledge and education about new materials. Another factor is that traditional building methods are often prioritized over innovative solutions because of time and budget restrictions.

Another challenge is that the construction industry, particularly the cement industry, resists innovative materials like alkali-activated geopolymers. The cement industry operates with a dominant position where it can influence fixing prices and controlling the market. The industry impacts regulations and academic research in favor of traditional cement.

P07: “In Europe, for instance, regulations ask for a minimum cement content, but in Australia, they are based on performance. The industry supports universities and concrete associations to keep traditional practices. There is a willingness; however, in the Netherlands for innovation. Institutes like the University of Delft are exploring R&D solutions to explore new materials”.

Some companies are willing to try something new. The problem is often the step from pilot projects to upscaling to business as usual. Recently the ‘normal’ concrete industry adopted the reality that there is working space for new types of binders in the concrete industry and that concrete with geopolymer binders should be addressed as concrete.

However, participants mentioned a shift in common attitudes toward sustainability. In recent years, such a shift has been mainly driven by regulations and potential benefits for the business within the construction sector.

P04: “Regulations require changes in favor of sustainability. I see that change is coming and that we are moving in a more sustainable direction. GPC is part of that direction”.

The common attitude in the construction industry is primarily based on profit. This is particularly the case for residential construction where individuals prefer to spend money on something over sustainability issues. However, there has been a shift in projects where the government is a client as they are inclined to pay extra money to invest in infrastructure sustainability, facilitating geopolymer concrete adoption in the future. About three years ago, geopolymer concrete usage was limited to small projects and there was skepticism about its applicability. Using geopolymer concrete in more projects with cooperation between contractors has gained trust in this innovative material.

P06: “Nowadays, they call for geopolymer concrete for every project, showcasing the major shift in attitudes compared to past years”.

Geopolymer concrete in the market is gaining increased acceptance. A low-carbon alternative to conventional concrete provides benefits in terms of sustainability, mainly CO2 emission reduction. Then, it is in line with green construction methods. GPC is considered a viable option to meet sustainability in construction projects, and the need for its usage is growing.

Prior conditions based on the DOI theory revealed key aspects influencing the adoption of alternative building materials. Practical experience with geopolymer concrete has a huge role in increasing knowledge and its continuous application for the next projects. This experience can be achieved through successful pilot projects while there is an ongoing evaluation of its performance. However, limited experience and previous unsuccessful projects with new materials might cause skepticism and hinder their adoption in the future. Besides, the willingness toward innovative materials shows a shift in attitudes as nowadays the industry has recognized the environmental benefits of geopolymer concrete such as CO2 emissions reduction. Despite the willingness, the conservative nature of the construction industry prioritizes conventional materials and methods. This is mostly because time and budget are two main limitations, causing to keep using traditional business models. Such challenges require updating regulations and industry collaboration to close the knowledge gap toward innovative materials.

4.3 To what extent do construction professionals' characteristics influence the knowledge regarding geopolymer concrete?

The last part addresses the third sub-question of how the characteristics of target individuals could influence the knowledge of innovative building materials. It delves into three elements of the DOI theory including socio-economic factors, personality variables, and communication behaviors. For question eight, participants were asked about the influence of four socio-economic factors on the knowledge level of innovative solutions. Those factors are introduced as age, gender, education, and income. After that, personality variables were investigated in question nine, where three personalities were examined. This question was designed to explore which environmentally concerned, technology-oriented, or leadership personalities could impact the most. The next two questions ten and eleven dealt with the communication behaviors of the target group. In doing so, interviewees were asked how the information about innovative materials is distributed in the construction sector. This was followed by question eleven where participants chose from potential sources of information. Those include sources such as recommendations from colleagues, self-searching, attending conferences, or social media. The next question asked interviewees whether there would be any additional information or factors that were not covered so they could share their insights even more. This question was created because every theoretical framework has its strengths and weaknesses. Therefore, incorporating this extra question provided participants' viewpoints to dive deeper into challenges regarding geopolymer concrete adoption.

Socio-economic factors

For the third part, elements of age, gender, education level, and income as socio-economic factors were explored. Participants' viewpoints showcased how those factors could influence the knowledge about innovations like geopolymer concrete. Most of the participants regarded age as a crucial factor. Seven interviewees highlighted that older professionals are more conservative and resist adopting new materials and innovations. On the other hand, young people usually tend to be open to changes and adopt alternative solutions.

P01: "Older people in construction are generally more conservative and reluctant to try new materials".

P03: "Older professionals may resist change; younger generations are more open".

P10: "Older people may be more resistant to change".

However, two participants mentioned that some older individuals might be innovative and willing to accept alternative materials.

P11: "The most innovative person I know in the concrete industry is above 70 years old".

Regarding gender, two participants mentioned that women are more interested and effective in initiating sustainability and supporting innovation.

P03: "Women are seen as effective in driving sustainability initiatives".

P04: “Females are usually more interested in sustainability”.
Other interviewees did not refer to any specific relation between gender and its influence on Knowledge about innovative materials.

The next factor is education where findings showed a positive relationship between its influence and knowledge level about innovation. Seven participants emphasized that higher education is associated with a better understanding of innovation benefits. Therefore, educated individuals are more informed when it comes to decision-making. As a result, they are willing to be open to new materials adoption.
P02: “Higher education correlates with understanding sustainability benefits”.
P04: “Education level could impact openness to innovation”.
P07: “Education is critical for implementing innovations”.

For income, four interviewees mentioned this factor in their responses. They highlighted the influence of this factor on knowledge level from two aspects. Companies with lower incomes have problems finding financial sources to explore innovations. This is because innovative solutions are usually expensive compared to conventional materials. Another aspect is about the connection of income with education level. Individuals with higher incomes have access to a higher education, indirectly impacting their knowledge level about innovations.
P01: “Lower incomes may struggle to afford consultants for new materials”.
P02: “Income may connect with higher education and informed decisions”.
P03: “Education level and income influence awareness of sustainable materials”.

A summary of participants’ responses for each socio-economic factor is shown in the table below.

Table 7 Participants’ responses for socio-economic factors

Participant	Response	Age	Gender	Education	Income
P01	Older people in construction are generally more conservative and reluctant to try new materials. Lower incomes may struggle to afford consultants for new materials. More knowledgeable individuals are cautious due to understanding limitations and risks.	√	×	×	√
P02	Higher education correlates with understanding sustainability benefits. Income may connect with higher education and informed decisions.	×	×	√	√
P03	Older professionals may resist change; younger generations are more open. Women are seen as effective in driving sustainability initiatives. Education level and income influence awareness of sustainable materials.	√	√	√	√
P04	Younger people are generally more open to change. Females are usually more interested in sustainability.	√	√	√	√

	Education level and income could impact openness to innovation.				
P05	Older individuals tend to be more conservative. Younger generations prioritize sustainability.	√	×	×	×
P06	Older professionals in the concrete industry are more conservative; Gender, education level, and income are not specified.	√	×	×	×
P07	Some young people can be resistant while older individuals could remain innovative. Education is critical for implementing innovations.	×	×	√	×
P08	Only the level of education impacts.	×	×	√	×
P09	Younger individuals are more willing but lack knowledge. Education and age influence discussions on new materials.	√	×	√	×
P10	Older people may be more resistant to change. Education and support are crucial to closing generational gaps in sustainability practices.	√	×	√	×
P11	The most innovative person I know in the concrete industry is above 70 years old. The main problem is to find funding for investment in concrete innovations.	×	×	×	×
Total		7	2	7	4

Personality variables

After the investigation of socio-economic factors, the influence of personality variables was identified. The next characteristic elements based on the DOI theory were categorized into three features environmental, technical, and leadership skills. Participants provided their viewpoints about how each feature could influence the adoption of new building materials. Seven participants highlighted that being environmentally concerned is a driving feature that initiates movement toward alternative materials. Individuals with this personality have concerns about the environmental impacts of conventional methods. They are aware of the potential benefits of new materials, pushing the innovation forward.

P01: “Environmental concern focuses on benefits”.

P10: “Concerns about the environmental impacts of traditional concrete cause an initiative toward new materials”.

P11: “Environmentally concerned is essential for starting an innovation”.

For the second personality feature, eight participants mentioned that being technology-oriented is a key to understanding innovation. Technical people have practical knowledge and expertise, enhancing the adoption process. They are equipped with relevant information and standards and know how to perform innovation. In addition, interviewees emphasized that communicating technical data is important. This assures knowledge about new materials can be distributed within the construction industry.

P03: “Technology knowledge is important for understanding the process”.

P06: “Having technical and practical expertise and the ability to communicate the knowledge is also important”.

P11: “Technology-oriented is focused on requirements according to standards”.

Findings revealed that all the factors push innovation forward. They act like a triangle where the lack of one of them hinders the adoption. Nine participants considered leadership skills a major factor in adopting new materials. Individuals as leaders play an important role in driving changes toward innovation. This characteristic is crucial for decision-makers as they can show the benefits of new materials, encouraging their application in real projects. They can also provide finances for projects by making long-term contracts prioritizing sustainability.

P02: "Government leadership and legislation have the most impact".

P05: "Leadership qualities are also important for decision-makers".

P08: "Long-term contracts with sustainability & maintenance aspects are the best incentive".

A summary of participants' responses for each personality variable is shown in the table below.

Table 8 Participants' responses for personality variables

Participant	Response	Environmental Concern	Technology Orientation	Leadership
P01	Environmental concern focuses on benefits, technology orientation on performance, and leadership on change. Collaboration combines vision, risk assessment, and change implementation.	√	√	√
P02	All the factors push innovation forward, but government leadership and legislation have the most impact. On a smaller scale, commitment to sustainability from individuals also matters.	√	√	√
P03	They act like a triangle so the lack of one of them hinders adoption. Environmental concerns for initiation, technology knowledge for understanding, and leadership for making changes are needed.	√	√	√
P04	I know several environmentally concerned people who hate concrete so much that making concrete more sustainable does not make them happy. And I know several smart people who are conservative and careful. So no, not particularly.	×	×	×
P05	Leadership qualities are also important for decision-makers. Everyone should be involved with different skills; you need technical, engineering, and financial. It is like a chain where it is strong as its weakest link.	√	√	√
P06	People with influential characteristics are essential to showcasing the benefits of new materials. Having technical and practical expertise and the ability to communicate the knowledge is also important.	×	√	√
P07	Cost is a significant key. If it is cheaper and environmentally friendly, people will adopt it. Leadership and healthy competition in the market matter; however, the concrete industry involves suppliers who dictate the	×	√	√

	quality. Another motivation is to be a pioneer in making cement-free structures.			
P08	Development costs money, who will pay the start-up costs? The market and contractors also need a financial incentive, from the local government, to develop and innovate. Long-term contracts with sustainability & maintenance aspects are the best incentive.	×	×	√
P09	All of them. Politicians also play a role in influencing the adoption. Stakeholders need to know about new materials. There is also a shift in leadership roles, with individuals from backgrounds in economics or other fields now leading organizations.	√	√	√
P10	Concerns about the environmental impacts of traditional building materials cause an initiative toward new materials. This issue is a major factor in urging the need for sustainable alternatives.	√	×	×
P11	Environmentally concerned is essential. Technology-oriented is focused on requirements according to standards and costs. Innovations require money and will not comply with the current standards. Without leadership focused on innovation the people working within the organization will remain focused on the old-fashioned way of working.	√	√	√
Total		7	8	9

Communication behaviors

The last characteristic investigated in this study was communication behaviors according to the DOI framework. Understanding communication behaviors contributes to identifying the main resources used for sharing information about new materials. Participants mentioned academic resources, professional networks, magazines and digital platforms, and social media as prevalent resources for distributing knowledge regarding innovative building materials.

Knowledge sharing in the construction sector starts with academic papers and pilot projects. Then pilot projects are published in technical publications and presented in seminars and conferences. Follow-up courses organized by the Betonvereniging help professionals reeducate themselves.
P04: “After that, courses are given by post-academic institutes and de Betonvereniging”.
P07: “This information is shared through workshops, conferences, and partially by the scientific community”.

Participants highlighted the role of professional networks in distributing knowledge where individuals trust in peer-to-peer recommendations. Such networks are made through meetings conducted by specific industry groups where individuals can exchange ideas and update their information about new materials.

Such groups offer courses on concrete and cement technologies and hold meetings to discuss recent trends. During regular meetings, participants are involved in communities for new materials evaluation.
P09: “Information is shared through organizations like the Concrete Society and specialized groups like STUTECH”.

Other sources of information, mentioned by the interviewees, are specific magazines and digital platforms. Magazines specialized in the cement and concrete industry provide invaluable updates about developments and trends for new materials in the concrete sector. These are considered reliable sources where individuals get information for practical applications. Digital platforms are another resource that professionals use through online searching. These are beneficial since they offer fast and easy access to developments and innovations in the concrete industry. Such platforms are considered a hub for sharing education and training. They enhance further innovation and development regarding new materials. Participants highlighted the importance of social media in showcasing the feasibility and benefits of new materials. LinkedIn, Stufib, and Stubeco, are social networking platforms where individuals share knowledge and discuss new materials.
P01: “We also have specific magazines such as Betoniek and Cement to share information amongst our peers”.
P09: “Platforms provide publications, events, and online resources within the concrete industry”.

However, sharing information in the industry is limited since companies tend to keep innovation close to prevent their competitors from using it against them. Even though some companies are open to showing specifications and results, the fine-tuning process and mixtures might remain confidential. Companies share knowledge only when the ingredients of their binder system are described as abstract.
P05: “The specifics of certain ingredients are confidential and not fully disclosed”.
P11: “The asset owners running the contracts are less willing to share information”.
This cautious approach derived from the competition in the concrete industry could hinder knowledge distribution and consequently influence the adoption of new materials.

The findings highlighted how the characteristics of construction professionals can influence the knowledge about innovative materials. Age and education are two main socio-economic factors as discussed in the interviews. Older generations tend to resist changes, so they are unwilling to adopt innovative materials over conventional methods. On the other hand, younger professionals and educated people are more open to innovation since they are informed about the potential benefits of such materials. Personality variables including environmentally concerned, technology-oriented, and leadership are important elements, impacting the adoption process. Environmentally concerned individuals care about sustainability and initiate innovation. Technical people understand the procedure and they can communicate the knowledge to other professionals. Leadership is also crucial as individuals with this trait promote the adoption and drive changes toward new materials. Communication behaviors such as academic papers, professional network, and digital platforms are common ways to distribute knowledge and trends about innovative materials. However, the competition might hinder the knowledge dissemination and adoption of new materials since companies tend to keep specific information confidential.

5. Discussion

This section addresses the main research question of this study by analyzing the findings. The data analysis process is conducted qualitatively by interpreting the responses from interviewees, presented in Chapter 4. This section is divided into three parts and deals with answering specific sub-questions of this research.

5.1 Awareness and knowledge of construction professionals about geopolymer concrete.

The first part delves into answering the first sub-question of this study. It explores the knowledge of construction professionals regarding geopolymer concrete as an innovative building material. The interpretation of responses is based on three knowledge forms awareness-knowledge, how-to-knowledge, and principle-knowledge from the DOI theoretical framework. However, it is important to mention that all interviewees were among the highly knowledgeable professionals in the construction sector. Although the interpretation of the findings, regarding the professionals' knowledge, might not be generalized to the whole industry, their valuable insights resulted in identifying the potential challenges toward geopolymer concrete adoption.

Awareness-knowledge

Participants' responses revealed that they have a solid awareness of geopolymer concrete as an alternative sustainable material. Their qualitative answers showcased their high familiarity with this innovative material by mentioning different aspects of it. Through the interviews, they highlighted the historical use of geopolymer concrete in other countries like Australia and Russia and how it was introduced in the Netherlands, following sustainability initiatives. They also mentioned pilot tests run by pioneer organizations like Betonakkoord to incorporate geopolymer concrete into the construction sector. This showcased their updated information about trends and developments regarding innovative building materials. This knowledge form is essential since it serves a foundation for awareness of innovation and sustainable alternatives in the Dutch construction industry.

How-to-knowledge

Going through the responses regarding the second knowledge form, the interviewees showed relevant knowledge about different types of binders for geopolymer concrete. Answering this question provides a piece of evidence that participants are aware of how to use innovative solutions in practice. As stated in the findings, they emphasized industrial by-products such as furnace blast slag and fly ash as common binders used in geopolymer concrete. In addition, they referred to the technical aspects and application procedures, underscoring their proficiency with geopolymer concrete. Some participants also mentioned companies specialized in providing specific binders, showcasing their practical knowledge about geopolymer concrete.

Principle-knowledge

Principle-knowledge is another knowledge level form where participants could answer the Why questions regarding the innovation. This is when they possess strong knowledge of alternative solutions, such as the advantages and disadvantages of using innovative building materials. Participants emphasized specific advantages of geopolymer concrete over traditional concrete, particularly CO_2 emission reduction and better resistance to acid and chemical attacks. They also added concerns about the disadvantages of geopolymer concrete because of uncertainties about its long-term performance, higher initial costs, and regulation issues. Analyzing the interviewees' responses highlighted the complex situation of geopolymer adoption where there is a need to balance its upsides with potential challenges in the construction industry.

5.2 Prior conditions and the knowledge gap about geopolymer concrete.

Findings about the prior conditions are investigated in the second part to answer the second sub-question. For each element derived from the DOI theoretical framework, the responses are analyzed to gather themes and patterns addressed by interviewees.

Previous experience and geopolymer adoption

Analyzing the findings showcased that previous experience positively influences innovative building materials adoption. Interviewees emphasized when there is hands-on experience with geopolymer concrete the chance of accepting the innovation and understanding its application increases. On the other hand, limited experience with such innovative materials is considered a major obstacle. This causes skepticism about the reliability of new materials and potentially hinders the adoption process. Participants highlighted conducting small projects when geopolymer concrete is used on a pilot scale and suggested its application in more projects. As a result, more performance data from successful project applications, followed by continuous testing and monitoring builds confidence toward geopolymer concrete adoption. This DOI element turned out to be significant in enhancing geopolymer concrete adoption.

Challenges in the construction industry

Responses emphasized that geopolymer concrete could mitigate issues the construction industry confronts such as CO_2 emission and environmental impacts. These issues initiate the usage of geopolymer concrete to provide sustainable solutions as alternative building materials. However, there are challenges involved in introducing such innovation. Participants highlighted the competitive use of precursors like blast furnace slag makes it challenging to access available materials for geopolymer concrete. Their responses are aligned with global concern regarding the availability of these waste by-products for geopolymer concrete in the future (Danish et al., 2022). In addition, concerns exist about conforming new materials with current standards and regulations, and lack of long-term performance data. Therefore, the growing demand for new materials requires support from regulation, education, and R&D solutions to increase the development process.

Willingness to innovativeness

Results indicate a growing willingness toward innovative solutions due to environmental concerns in the construction industry. Despite negative viewpoints about new materials a few years ago, there has been a shift in attitudes in recent years. This shift in mindset is associated with realizing the high CO_2 emission of traditional materials like Portland cement and the need for alternatives. Nowadays, more clients and contractors are interested in using geopolymer concrete as an alternative building material. However, findings revealed that potential risks and initial costs caused the industry to be cautious regarding its adoption.

Attitudes within the construction industry about innovative materials

Exploring the findings showed a consensus with studies about the conservative nature of the construction sector toward innovation (Akadiri, 2015). This is because multiple stakeholders are involved within the industry, where time and budget limitations are barriers to choosing new materials. In addition, this sector prioritizes profit margins and is not inclined to take potential risks and incur costs of trying new materials. Consequently, this results in sticking with conventional materials and methods of construction. Besides, resistance remains within the cement industry regarding new materials where they can influence the market price and regulations in favor of conventional materials. On the other hand, regulations require the construction sector to lower its environmental impact, and the beneficial application of new alternatives has led to changes. Consequently, these drivers gradually reshaped the common attitudes about the innovative solution. As a result of the growing need for alternative materials, companies, and research institutes are taking the lead in exploring new materials like geopolymer concrete.

5.3 Influence of target professionals' characteristics on knowledge about innovative materials.

This part discusses the findings regarding the influence of target individuals' characteristics on the knowledge about innovation. Analyzing the responses to three attributes of socio-economic factors, personality variables, and communication behaviors revealed the significance of each factor. Furthermore, additional information is presented afterward when participants highlight specific challenges, influencing the knowledge and adoption of innovative building materials.

Socio-economic factors

The socio-economic factors of this study are age, gender, education, and income. The findings show the important role of each factor, and which one could impact the most on shaping knowledge about innovation. Regarding age, participants emphasized that younger professionals are more likely to adopt new materials as they are more open to innovation. Older individuals often resist changes and take a reserved approach toward new materials. Participants mentioned that the younger generation has more affinity with trends, developments, and education where they are exposed to environmental issues. Although there is no specific study to showcase such factors in the construction industry, the findings can be validated by exploring other related industries. Industries such as energy, IT, and electronics with direct links with construction could be used as some evidence. Several studies in multiple sectors such as energy production (Nygren et al., 2015), internet, and IT (Molodovan et al., 2015; Lee, 2014) have shown the positive impact of young professionals on innovations. Although age is often considered a significant factor, older professionals could exist with openness toward innovations. Most of the responses showed no distinct gender specifications to influence the knowledge of innovative materials. However, women are considered effective in driving sustainability issues. They are more likely to accept jobs in sustainability as they are open and interested in this field.

Education is also crucial as participants emphasized the strong relationship between this factor and the level of knowledge. Educated individuals have a deeper understanding of innovative solutions and as a result, they are more open to them. This finding is aligned with studies exploring innovation in the IT and electronic sector where education has a positive influence (Molodovan et al., 2015; Lee, 2014). Participants highlighted professionals with higher education are well-informed about the benefits and practical application of new materials, resulting in a higher chance of their adoption. Analyzing the data findings, income is another factor that could indirectly impact the knowledge level about innovations. income could connect to higher education because of more access to resources to explore new materials. On the other hand, low-income levels with limited finances have difficulty investing in consultation and experimentation of innovations.

Personality variables

Findings showed how personalities driven by environmental, technological, and leadership traits influence innovative materials adoption. Environmentally concern is crucial as individuals with this personality focus on the ecological benefits of implementing innovations. Their concern about environmental issues of conventional materials causes initiatives for exploring new materials and sustainable alternatives. Technology-oriented characteristic plays a key role in understanding innovation procedures. Individuals equipped with this mindset can assess the performance of new materials and they have practical expertise. It is also important that this personality is better combined with communication abilities to transfer knowledge about new materials.

Studies show that environmental concern, technology orientation, and leadership opinion are necessary traits to disseminate innovation on a larger scale (Dedehayir et al., 2017). The data analysis revealed that all three factors are essential for innovation adoption, but participants emphasized leadership as a driving quality. This trait is important for decision-makers who can showcase the benefits of adopting new materials. Another challenge is the initial cost so the leaders in the government can encourage new materials implementation through financial incentives. Having a leadership perspective leads to making changes, without it, organizations and companies continue working on traditional methods.

Communication behaviors

Identifying the distribution methods for innovation trends is beneficial in bridging the knowledge gap about new materials in the construction sector. Interpreting the responses, formal channels such as specific specialized magazines, Cement and Betoniek, seminars and conferences are primary sources. Through these channels updates about innovative materials and research findings are shared with professionals. Recommendations from peers and colleagues are another valuable source mentioned by interviewees. This is where professionals share their knowledge and insights through trusted peer-to-peer communication. This source of information indicates the significance of professional networks in knowledge distribution.

Individuals are more likely to adopt innovation when they receive recommendations from peers and have more contact with professionals (Dedehayir et al., 2017). Participants also referred to social media and online platforms as other important sources. They mentioned examples of LinkedIn, Stufib, and Stubeco as social networks and webinars, where there is a potential environment for sharing knowledge and information. Such digital sources provide platforms where access to information about new materials is fast and convenient. However, findings denote a limitation in knowledge sharing since companies tend to keep their innovation confidential due to competition within the industry. They are reluctant to share information and open knowledge about specific details of new materials. Consequently, this could hinder the adoption of innovative materials.

Additional insights

Through the interviews when participants were asked about any additional insights, they highlighted challenges for new materials adoption like geopolymer concrete. Exploring themes and patterns from their responses provided valuable information as presented below:
Regulation and financial initiative: Regulations and standards are based on traditional materials and methods. Updating regulations where new materials conform to the standards promotes their adoption (ref.). Initial cost is another challenge particularly to scale-up innovations. Participants highlighted the significance of subsidies, CO_2 taxation, and long-term contracts with sustainability to encourage implementing alternatives.

Pilot projects and research: The more research and pilot projects are conducted; the more long-term performance data are available. Understanding the long-term performance leads to gaining trust so that professionals are more confident using new materials. Responses emphasized that real experience is needed with alternative materials, showcasing their application benefits like geopolymer concrete.

Resistance to change: There is a recurring theme through the responses about the reserved nature of the construction industry where people do not want to change the traditional methods (ref.). Structural engineers, for instance, take additional safety margins because of uncertainty issues and professionals are cautious about innovations. Participants suggested collaboration, active communication, and providing tangible evidence of benefits to mitigate uncertainties and perceived risks of new materials.

Knowledge and education: After conducting pilot projects, they should be well-documented. Then, the knowledge attained through practical experience must be distributed within the construction industry. This approach could create an open knowledge environment about new material applications. Another challenge is convincing engineers and clients about new materials as they have concerns about the viability and risks associated with alternatives due to insufficient knowledge. This emphasizes the need for education and knowledge distribution.

Materials availability: The availability of precursors for geopolymer concrete is challenging because of materials scarcity. In addition, the competition within the industry in using materials like blast furnace slag is another issue. The participants suggested utilizing local resources to address the global shortage of raw materials. Using local materials also results in mitigating the environmental impacts of transportation from abroad.

6. Conclusions and recommendations

6.1 Conclusions

This study aimed to answer the main research question of how the knowledge gap among construction professionals influences the adoption of geopolymer concrete in the Dutch construction industry. Conducting a qualitative data analysis gathered from semi-structured interviews resulted in identifying key findings. These findings contributed to answering three sub-questions of this study.

Regarding the first sub-question about the knowledge level of construction professionals, all the interviewees have solid expertise and knowledge regarding alternative materials like geopolymer concrete. Although their knowledge and awareness could not represent the whole construction industry, they referred to challenges regarding awareness about new materials. For instance, a lack of sufficient knowledge among structural engineers causes them to take extra safety margins. This is because they are skeptical of potential risks and uncertainties associated with new materials application.

Answering the second sub-question about the influence of prior conditions, the research reveals that prior experience is a positive factor in adopting new materials. However, data analysis showed several elements contributing to the knowledge gap about geopolymer concrete. While geopolymer concrete is considered an alternative low-carbon building material with environmental benefits, addressing current challenges should be factored in. Without sufficient application of geopolymer concrete in real construction projects, there is not enough data on its long-term performance. In addition, regulations are mainly based on traditional materials like Portland cement and alternative materials do not conform with existing standards. Another issue is the availability of the materials needed for making geopolymer concrete such as precursors. The shortage of materials like blast furnace slag causes challenges in producing geopolymer concrete.

The third sub-question aimed to answer the impact of target individuals' characteristics on adopting innovations like geopolymer concrete. This study delved into socio-economic factors, personality variables, and communication behaviors to explore their influence on the level of knowledge toward innovation. The findings showed that younger professionals are more open to innovation because of their involvement with environmental issues and education. This is also the case with education where educated individuals better understand new materials applications since they are informed about relevant advantages. In addition, higher income could indirectly connect to education as more resources are available to develop innovation. Analyzing responses for personality variables, all three features of environmental, technological, and leadership skills are crucial to implementing innovative solutions. When environmentally concerned initiate an innovation, technical individuals assist in understanding and communicating its application. Leadership skills are also important, particularly for decision-makers. Findings emphasized this characteristic since it is essential to make changes in favor of innovation and encourage the construction sector by giving subsidies and financial incentives. In addition, results highlighted the importance of formal channels like specific magazines, seminars, and informal communication such as social media and peer-to-peer recommendations to enhance information sharing.

However, the conservative nature of the construction sector hinders innovative materials adoption because of the competition. Companies are not willing to share detailed information about their specific materials. In addition, this is a project-based industry where cost and time limits are two challenges for knowledge distribution. In addition, applying the DOI theory provided a proper lens to investigate the key points about innovative materials applications like geopolymer concrete. It assisted in exploring the main elements contributing to challenges regarding awareness and usage of new materials. This framework was also followed by an open question where participants shared their insights about other aspects that might not be covered by the given method, enriching the findings of this study.

6.2 Limitations

This study encountered some limitations when researching the knowledge level of construction professionals for some reason. One of the limitations could be the sample size of this research as it might not represent the whole individuals within the construction industry. The implementation of this study depends on the cooperation and willingness of the target participants. Despite all efforts to approach professionals in different roles, the majority did not proceed with conducting interviews. Consequently, there might not be enough participants willing to participate in the semi-structured interviews, impacting the depth and quality of the study. However, this study gathered invaluable data from highly knowledgeable participants who specialized in the concrete industry.

Besides, although this successfully identified key points regarding the knowledge level and challenges for geopolymer concrete, there were still areas for development. This is because of the time constraint of such research. One of the areas that has not been covered is providing strategies and solutions for facilitating knowledge distribution in the construction industry.

6.3 Recommendations for future research

For future research, it is recommended to explore the role of regulation and standard frameworks on geopolymer concrete adoption. This approach could include investigating current regulatory procedures regarding new materials implementation. In addition, future studies could involve updating regulations and how this influences geopolymer concrete application in real projects. Regarding the theoretical framework, using the diffusion of innovation (DOI) theory led to identifying the key findings. However, conducting future research based on other frameworks could be beneficial. Theories such as the technology acceptance model (TAM) and theory of planned behavior (TPB) could provide additional factors involved in geopolymer concrete adoption.

Further studies could focus on communication strategies and explore their potential effectiveness on knowledge distribution toward innovation. Reaching an open knowledge environment where information about new materials is shared without restriction is crucial to enhancing their adoption. Exploring challenges and providing solutions to achieve such an environment could benefit the adoption process. Besides, conducting a comparative analysis is recommended with different countries, where multiple regulations and attitudes exist toward new materials applications like geopolymer concrete.

References

Ahmad Wani, T., & Wajid Ali, S. (2015). Innovation Diffusion Theory Review & Scope in the Study of Adoption of Smartphones in India Journal of General Management Research. Journal of General Management Research, 3, 101-118.

Ahmed, A. M., Sayed, W., Asran, A., & Nosier, I. (2023). Identifying barriers to the implementation and development of sustainable construction. International Journal of Construction Management, 23(8), 1277-1288.

Ahn, Y.H.; Pearce, A.R.; Wang, Y.; Wang, G. Drivers and barriers of sustainable design and construction: The perception of green building experience. Int. J. Sustain. Build. Technol. Urban. Dev. 2013, 4, 35–45.

Akadiri, P. O. (2015). Understanding barriers affecting the selection of sustainable materials in building projects. Journal of Building Engineering, 4, 86-93.

Akhtar, N., Ahmad, T., Husain, D., Majdi, A., Alam, M. T., Husain, N., & Wayal, A. K. S. (2022). Ecological footprint and economic assessment of conventional and geopolymer concrete for sustainable construction. Journal of Cleaner Production, 380, 134910.

Almutairi, A. L., Tayeh, B. A., Adesina, A., Isleem, H. F., & Zeyad, A. M. (2021). Potential applications of geopolymer concrete in construction: A review. Case Studies in Construction Materials, 15, e00733.

Amaral, R. E., Brito, J., Buckman, M., Drake, E., Ilatova, E., Rice, P., ... & Abraham, Y. S. (2020). Waste management and operational energy for sustainable buildings: a review. Sustainability, 12(13), 5337.

Amran, Y. M., Alyousef, R., Alabduljabbar, H., & El-Zeadani, M. (2020). Clean production and properties of geopolymer concrete; A review. Journal of Cleaner Production, 251, 119679.

Baumann, H.; Boons, F.; Bragd, A. Mapping the green product development field: Engineering, policy and business perspectives. J. Clean. Prod. 2002, 10, 409–425.

Betonakkoord. (2023, December 19). Start laatste fase Betonakkoord. Betonakkoord. https://www.betonakkoord.nl/2023/12/19/start-laatste-fase-betonakkoord/

Castel, A., & Foster, S. J. (2015). Bond strength between blended slag and Class F fly ash geopolymer concrete with steel reinforcement. Cement and Concrete Research, 72, 48-53.

Danish, A., Ozbakkaloglu, T., Mosaberpanah, M. A., Salim, M. U., Bayram, M., Yeon, J. H., & Jafar, K. (2022). Sustainability benefits and commercialization challenges and strategies of geopolymer concrete: A review. *Journal of Building Engineering*, *58*, 105005.

Das, S., Mohapatra, A. K., & Rath, A. K. (2014). Geo-polymer concrete–Green concrete for the future—A review. International Journal of Civil Engineering Research, 5(1), 21-28.

de Azevedo, A. R., Marvila, M. T., Tayeh, B. A., Cecchin, D., Pereira, A. C., & Monteiro, S. N. (2021). Technological performance of açaí natural fibre reinforced cement-based mortars. Journal of Building Engineering, 33, 101675.

Dedehayir, O., Ortt, R. J., Riverola, C., & Miralles, F. (2017). Innovators and early adopters in the diffusion of innovations: A literature review. International Journal of Innovation Management, 21(08), 1740010.

Farooq, F., Jin, X., Javed, M.F., Akbar, A., Shah, M.I., Aslam, F., Alyousef, R., 2021. Geopolymer concrete as sustainable material: a state of the art review. Construct. Build. Mater. 306, 124762.

Gartner, E. (2004). Industrially interesting approaches to “low-CO2” cements. Cement and Concrete research, 34(9), 1489-1498.

Greenhalgh, T., Robert, G., Macfarlane, F., Bate, P., Kyriakidou, O. and Peacock, R. (2005), “Storylines of research in diffusion of innovation: a meta-narrative approach to systematic review”, Social Science and Medicine, Vol. 61 No. 2, pp. 417-430.

Hassan, A., Arif, M., & Shariq, M. (2019). Use of geopolymer concrete for a cleaner and sustainable environment–A review of mechanical properties and microstructure. Journal of cleaner production, 223, 704-728.

He, J., Jie, Y., Zhang, J., Yu, Y., & Zhang, G. (2013). Synthesis and characterization of red mud and rice husk ash-based geopolymer composites. Cement and Concrete Composites, 37, 108-118.

Hwang, B. G., Shan, M., & Lye, J. M. (2018). Adoption of sustainable construction for small contractors: major barriers and best solutions. Clean Technologies and Environmental Policy, 20, 2223-2237.

Iyer-Raniga, U.; Erasmus, P.; Huovila, P.; Maity, S. Circularity in the Built Environment: A Focus on India. In International Business, Trade and Institutional Sustainability; Leal Filho, W., Borges de Brito, P., Frankenberger, F., Eds.; Springer International Publishing AG: Cham, Switzerland, 2020; pp. 739–755.

Kumar, A., Saravanan, T. J., Bisht, K., & Kabeer, K. S. A. (2021). A review on the utilization of red mud for the production of geopolymer and alkali activated concrete. Construction and Building Materials, 302, 124170.

Lee, S. Y. (2014). Examining the factors that influence early adopters’ smartphone adoption: The case of college students. *Telematics and Informatics*, *31*(2), 308-318.

Mantese, G. C., & Amaral, D. C. (2017). Comparison of industrial symbiosis indicators through agent-based modeling. Journal of Cleaner Production, 140, 1652-1671.

Meyer, G., 2010. International perspectives diffusion methodology: Time to innovate, Journal of Health Communication, (2014 Oct), pp. 27-41.

Moldovan, S., Steinhart, Y., & Ofen, S. (2015). “Share and scare”: Solving the communication dilemma of early adopters with a high need for uniqueness. *Journal of Consumer Psychology*, *25*(1), 1-14.

Nagajothi, S., & Elavenil, S. (2021). Effect of GGBS addition on reactivity and microstructure properties of ambient cured fly ash based geopolymer concrete. Silicon, 13(2), 507-516.

Nygrén, N. A., Kontio, P., Lyytimäki, J., Varho, V., & Tapio, P. (2015). Early adopters boosting the diffusion of sustainable small-scale energy solutions. *Renewable and Sustainable Energy Reviews*, *46*, 79-87.

Petri, I., Beach, T., Rezgui, Y., Wilson, I. E., & Li, H. (2014). Engaging construction stakeholders with sustainability through a knowledge harvesting platform. Computers in Industry, 65(3), 449-469.

Petzek, E.; Todu¸ti, L.; Băncilă, R. Deconstruction of Bridges an Environmental Sustainable Concept. Procedia Eng. 2016, 156, 348–355.

Poudenx, P. (2008). The effect of transportation policies on energy consumption and greenhouse gas emission from urban passenger transportation. Transportation Research Part A: Policy and Practice, 42(6), 901-909.

Puertas, F., Martínez-Ramírez, S., Alonso, S., & Vázquez, T. (2000). Alkali-activated fly ash/slag cements: Strength behaviour and hydration products. Cement and concrete research, 30(10), 1625-1632.

Rogers, E.M., 1983. Diffusion of innovations. 3Rd ed. New York: Free Press.

Rogers, E.M., 2003. Diffusion of innovations. 5th ed. New York: Free Press.

Sahin, I. (2006). Detailed review of Rogers' diffusion of innovations theory and educational technology-related studies based on Rogers' theory. Turkish Online Journal of Educational Technology-TOJET, 5(2), 14-23.

Shahidan, S., Tayeh, B. A., Jamaludin, A. A., Bahari, N. A. A. S., Mohd, S. S., Ali, N. Z., & Khalid, F. S. (2017, November). Physical and mechanical properties of self-compacting concrete containing superplasticizer and metakaolin. In IOP Conference Series: Materials Science and Engineering (Vol. 271, No. 1, p. 012004). IOP Publishing.

Shen, L.-Y.; Tam, V.W.Y.; Tam, L.; Ji, Y.-B. Project feasibility study: The key to successful implementation of sustainable and socially responsible construction management practice. J. Clean. Prod. 2010, 18, 254–259.

Singh, B., Ishwarya, G., Gupta, M., & Bhattacharyya, S. K. (2015). Geopolymer concrete: A review of some recent developments. Construction and building materials, 85, 78-90.

Talakokula, V., & Bhalla, S. (2016). Non-destructive strength evaluation of fly ash based geopolymer concrete using piezo sensors. Procedia Engineering, 145, 1029-1035.

Tokbolat, S., Karaca, F., Durdyev, S., & Calay, R. K. (2020). Construction professionals' perspectives on drivers and barriers of sustainable construction. Environment, Development and Sustainability, 22, 4361-4378.

Vakola, M., & Wilson, I. E. (2004). The challenge of virtual organisation: critical success factors in dealing with constant change. Team Performance Management: An International Journal, 10(5/6), 112-120.

Verma, M., Dev, N., Rahman, I., Nigam, M., Ahmed, M., & Mallick, J. (2022). Geopolymer concrete: a material for sustainable development in Indian construction industries. Crystals, 12(4), 514.

Weerapperuma, U., Jayasena, S., Rathnasinghe, A., & Thurairajah, N. (2022). The impact of professionals' knowledge on innovation adoption in the construction industry: A critical literature review.

Wongsa, A., Siriwattanakarn, A., Nuaklong, P., Sata, V., Sukontasukkul, P., & Chindaprasirt, P. (2020). Use of recycled aggregates in pressed fly ash geopolymer concrete. Environmental Progress & Sustainable Energy, 39(2), e13327.

Yaseri, S., Hajiaghaei, G., Mohammadi, F., Mahdikhani, M., & Farokhzad, R. (2017). The role of synthesis parameters on the workability, setting and strength properties of binary binder based geopolymer paste. Construction and Building Materials, 157, 534-545.

Appendix I

Consent Form for Exploring Knowledge in Geopolymer Concrete Adoption in the Dutch Construction Industry

Please tick the appropriate boxes	Yes	No
Taking part in the study		
I have read and understood the study information dated [28/12/2024]. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	□	□
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	□	□
I understand that taking part in the study involves the participant a survey questionnaire completed by the participant	□	□
Use of the information in the study		
I understand that information I provide will be used solely for academic purposes	□	□
I understand that personal information will not be collected about me that can identify me, such as my name or where I live.	□	□
Future use and reuse of the information by others		
I give permission for the survey database to be archived in University of Twente MS Teams OneDrive so it can be used for future research and learning. Access restrictions will apply to the data in the future that exclude commercial use and apply safeguarded access.	□	□

Signatures

……………… ______________________

Name of participant [printed] Signature Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Mohammad Hasan Aliyar Zanjani ______________________

Researcher name [printed] Signature Date

Study contact details for further information: Mohammad Hasan Aliyar Zanjani
m.h.aliyarzanjani@student.utwente.nl

Contact Information for Questions about Your Rights as a Research Participant

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee/domain Humanities & Social Sciences of the Faculty of Behavioural, Management and Social Sciences at the University of Twente by ethicscommittee-hss@utwente.nl

Appendix ll

Introduction

Thank you for participating in this research about Geopolymer (low carbon) Concrete (GPC) in the Dutch construction industry. Your input is invaluable in contributing to the advancement of sustainable building practices. This research explores factors contributing to the adoption of GPC as a sustainable alternative in construction projects within the Netherlands. Delving into the key factors influencing stakeholders' attitudes, this study aims to facilitate informed decision-making and drive positive change in the construction sector. Your insights will be crucial in identifying factors and pathways for promoting sustainable building materials like GPC. Together, we can pave the way for a more sustainable future in the Dutch construction industry.

1. Could you please tell me about geopolymer concrete as a building material?
2. If you were to choose a geopolymer concrete binder for a project, could you please refer to the different types of binders used? (Optional)
3. From your point of view, what are the advantages or disadvantages of using geopolymer concrete compared to traditional concrete?
4. How do you think previous experience with using sustainable building materials can influence their adoption in the future? (Optional: If you have experience with sustainable concrete, please mention)
5. What are the challenges in the Dutch construction industry that you think geopolymer/sustainable concrete could address or alleviate?
6. Do you think there is a willingness to explore innovative solutions like geopolymer concrete?
7. What are the common attitudes within the construction industry regarding innovations such as geopolymer concrete? In what ways they could influence the adoption of such building materials?
8. Do you think factors such as age, gender, education level, or income influence the level of knowledge about innovations like geopolymer concrete?
9. How do you think being environmentally concerned, and/or being technology-oriented, and/or having a leadership perspective may influence the adoption of new building materials?
10. Could you describe how information about innovative building materials is shared in the construction industry?
11. Which of the following sources contribute to providing information towards innovative materials: recommendations from peers, internet searching, attending conferences, or social networking? (Please feel free to choose as many as you want)
12. Feel free to share any additional insights on the adoption of innovations like geopolymer concrete in the Duch construction industry.
13. Could you please tell me about some demographic such as your position, years of experience, and education? (Optional)

Please feel free to skip any questions you do not want to answer.

Thank you for your valuable insights.