UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

DIT 801 - THE ROLE OF ALTERNATIVE BUILDING TECHNOLOGIES IN SUSTAINABLE HUMAN DEVELOPMENT IN THE CONTEXT OF SOUTH AFRICA

Courtney Shaw

M(Prof) Arch

Supervised by Dr Coralie van Reenen

Understanding the need for a comparative framework when selecting an appropriate building technology for sustainable human settlements in South Africa.

Department of Architecture
Faculty of Engineering, the Built Environment and Information Technology
University of Pretoria
South Africa

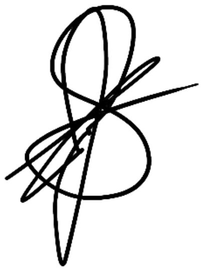
24 July 2023

DECLARATION OF ORIGINALITY

I declare that the mini-dissertation, ***Understanding the need for a comparative framework when selecting an appropriate building technology for sustainable human settlements in South Africa***, which has been submitted in fulfilment of part of the requirements for the module of **DIT 801**, at the University of Pretoria, is my own work and has not previously been submitted by me for any degree at the University of Pretoria or any other tertiary institution.

I declare that I obtained the applicable research ethics approval in order to conduct the research that has been described in this dissertation.

I declare that I have observed the ethical standards required in terms of the University of Pretoria's ethic code for researchers and have followed the policy guidelines for responsible research.



Signature:

Date: 24 July 2023

Supervisor: Dr Coralie van Reenen

Co-researcher: Ms Cecilia Snyman

ABSTRACT

By investigating the mechanisms behind environmentally sustainable construction technologies, designers and other critical stakeholders could gain a more comprehensive, holistic understanding of the implications for certain design and implementation decisions during a building's life have on the larger environment. In the context of South Africa, innovative building technologies offer a new means of combating the carbon footprint of human activities and settlement development, producing in the building industry, on resources and the natural environment. By conducting a comparative study of present IBT systems against the existing traditional form of brick-and-mortar construction, potential embodied energy savings in material selection will be investigated and form the basis for recommendations for future studies regarding environmentally sustainable human development.

KEYWORDS

- Alternative/Innovative building technologies
- Innovation
- Human Settlements
- Sustainability
- South Africa
- Conventional Building Technologies
- Embodied Energy

Contents

List of Figures

List of Tables

List of Abbreviations

ABT	Alternative Building Technology
BEST	Built Environment Sustainability Tool
CSIR	Council for Scientific and Industrial Research
DHS	Department of Human Settlements
DSI	Department of Science and Innovation
GBCSA	Green Building Council South Africa
GHG	Greenhouse Gas Emissions
HDA	Housing Development Agency
IBT	Innovative Building Technology
NBR	National Building Regulations
NHBRC	National Home Builders Registration Council
NHFC	National Housing Finance Corporation
NRCS	National Regulatory for Compulsory Standards
SHRA	Social Housing Regulatory Authority
UHI	Urban Heat Island

1 STUDY INTRODUCTION

Urbanisation - As more of the population moves towards the urban setting, the inevitable growing demand for adequate human settlement development across the world cannot be ignored by governments, the public sector, and environmental stakeholders alike. Along with this projected growth comes both exponential opportunity and potential challenges across sectors.

In 2021, The construction industry made up about 12% of the global gross domestic product (GDP) with an estimated annual growth of 3.6% expected between 2022 and 2030 (Tomorrow's World Today, 2021). Therefore, as part of the built environment, buildings and settlements play a critical role in the overall sustainability of human activity. Consequently, it becomes important for representatives of the industry such as architects, construction developers, and specialists as well as the country at large such as government, policy makers and end-users to engage in multi-disciplinary collaborations to achieve solutions to growing settlement problems in the most efficient, cost effective and sustainable manner possible.

Both practical and academic avenues that seek to initiate conversations and improve knowledge transfer must be uncovered and further developed to address inadequate policy and assist professionals in overcoming barriers that hinder efforts made towards more sustainable human activity in South Africa.

This report forms part of a larger collaborative research investigation to develop a suitable framework (Framework for Innovation and Transformative Technologies) and roadmap (Science Technology and Innovation for Sustainable Human Settlements Roadmap) for maintainable community growth through the joint efforts of the Council for Scientific and Industrial Research (CSIR), the Department of Human Settlements (DHS) and the Department of Science and Innovation (DSI) (van Reenen, 2023).

It is the intention of this enquiry to identify and examine how critical access to information and comparative frameworks can aid in producing informed, sustainable settlement development within the South African context. By comparing the energy consumption properties of innovative building technologies (IBT's) in relation to the current accepted traditional building techniques, this investigation aims to show the lower energy consumption potential offered by new building systems in an effort to counter the negative impact of the inevitable increase in human activity and settlement development whilst simultaneously ensuring sustainability across the built and natural environment.

2 LITERATURE REVIEW AND BACKGROUND

2.1 Introduction

South Africa is evidently one of the most urbanised countries in Africa with an urban population of approximately 67% and a projected increase to 80% by 2050 (UN-HABITAT, n.d.). Along with this trend towards urban migration, a variety of challenges accompany development such as ensuring adequate and equal access to infrastructure, service delivery, and sufficient housing (URBANET, 2020).

The latest statistics regarding the housing backlog in South Africa are not positive, and will proceed to become more severe over the next few years should it not be adequately addressed soon. As of 2019, South Africa is short of over 2.4 million houses across the country (SA Government, 2019). Due to ongoing rapid expansion across the nation, the need for fast, affordable, and safe housing solutions is of growing importance to the Department of Human Settlements.

In South Africa, Innovative Building Technologies (IBTs) have the potential to contribute towards solving this crisis due to their clean, rapid construction and potential reduced material requirement. Yet the uptake across the construction industry has been slow-to-none. To better understand the current position of IBTs in South Africa, one must first understand the current contextual discourse surrounding technological advancement in the built environment.

Concurrent to rapid urban growth, the average global surface temperature is expected to rise by +1.5°C, resulting in extreme weather events such as heatwaves and increased periods of drought to name a few (IPCC,2021). Thus, there has been a call for countries to drive more sustainable means of development to mitigate the inevitable impact on global climate systems due to human activity. Organisations such as the United Nations (UN) have developed strategies and Sustainable Development Goals (SDGs) to be achieved over the next thirty to fifty years to collectively combat the issue of climate change.

With the aforementioned conditions in mind, the responsibilities of critical role players; and the relationship between innovative building technologies and sustainability must be better understood to potentially support supplementary means of addressing urban issues across both developed and developing economies.

2.2Urbanisation and Climate Change

Urbanisation and densification of cities is not a new phenomenon. However, the implications of more people flocking to opportunities presented by the city are becoming increasingly apparent and severe. By 2030, it is estimated that over 71% of South Africa's total population will be situated in or near the city (SANSA, 2019). With this exponential migration comes a rise in the demand rate for housing, social infrastructure as well as an increase in ambient temperatures due to the urban-heat island (UHI) effect[1] which has dangerous effects on human wellbeing, infrastructure, and environmental systems (Li et al, 2022).

This rate of urbanisation has led to the unbalanced development of cities, with developing countries such as South Africa being more susceptible to the negative effects of inadequate planning and resource management (Li et al, 2022). Some of these issues include the formation of informal housing settlements closer to economic opportunities offered in the city, with many individuals and families living in unsafe and unhealthy conditions with little to no access to adequate essential services.

The vulnerability[2] of individuals in these urban regions, such as the City of Tshwane, increases when housing and service delivery cannot keep up with the demand, thus exacerbating the intensity of poverty and inequality (Alexander, 2021). Climate change further increases urban vulnerability as the frequency of extreme weather events increases, water and food sources are impacted by extreme heat and drought and flooding has major implications on infrastructure and housing – especially informal housing which makes up a large portion of the existing housing types around city hubs (Centre for Affordable Housing in Africa, 2022).

Thus, the need to find suitable, rapid solutions to support sustainable and safe human settlement development is imperative to overcoming the current and future impacts of further densification and climate change across communities.

[1] The Urban Heat Island effect is a phenomenon experienced in dense built-up areas due to the high presence of human activity producing heat such as cars and industrial processes, and the high insulation quality of buildings to retain heat gained during the day from solar exposure. This results in hot air being trapped in urban centres thus increasing the ambient temperature in comparison to the less urban surrounding areas (National Geographic Society, 2022).

[2] Vulnerability – in the context of this report, vulnerability refers to the predisposition of an individual or group to be affected by exposed risks and hazards brought about by climatic and urban conditions (IPCC 2022).

2.3Sustainable Human Settlement Development

Sustainability is a term made mention of across various industries. It encompasses a wide range of influences, stakeholders and has implications across regional, national, and global scales. To better understand the idea of sustainability within the built environment, a more in-depth definition must be established.

The United Nations Brundtland Commission of 1987 defines sustainability as: "the ability to meet the needs of the present without compromising the ability of future generations to meet their own needs". As a broad concept, it consists of four core pillars – Human, Social, Economic and Environmental Sustainability (Goodland, 2002). Ideally, to achieve sustainability overall, all four pillars must be addressed. For this study, specific focus will be placed on *Environmental Sustainability* and the role of IBT's in achieving a more environmentally sustainable solution (in comparison to traditional building practices) to rapid human settlement development within the climate and economic context of South Africa.

Environmental sustainability is defined as "ensuring that the needs of the current population are met without compromising the needs of future generations when considering natural capital[3]" (RMIT University, 2017). To achieve environmental sustainability, the resources within a particular situation must be sustainably consumed. This requires people to have a clear understanding of the biophysical limitations of their immediate environment to decide how best to utilise resources as well as manage waste emissions within the environment's capacity without impacting a community's ability to do so in the future (Goodland,2022).

Greenhouse gas (GHG) emissions as a result of anthropogenic activities, especially concentrated instances such as those found in urban areas, are an influential driver in the outcome of climate change and thus the effect of human development on the environment plays a pivotal role in environmental sustainability (Dos Santos, 2016). Therefore, a continuation in producing large carbon footprints of urban growth can thus have strong negative implications on environmental sustainability goals and objectives now and in the future.

[3] Natural capital – Any natural resource such as air, minerals, water, or land useful to human development (RMIT University, 2017).

2.4Measuring Sustainability in the Built Environment

According to the Intergovernmental Panel on Climate Change (IPCC) 2014 report, the built environment accounts for 32% of the final energy usage and 18% of the total carbon emission (2010) across all global human activities (IPCC,2014). Therefore, mitigation strategies within the construction and built industry may have a large, long-term impact on sustainable human development across the world if implementation strategies are executed correctly.

This brings to light the opportunity to revise current construction practice and policies to better accommodate the overall human settlement development goals set out by the United Nation's Sustainable Development Goals (SDG's) by taking a closer look at how buildings are designed as well as the carbon-energy impact of materials and techniques implemented. With reference to Figure 1, efforts towards reaching these objectives will be focused on *Goal 9: Industry, Innovation and Infrastructure*, *Goal 11: Sustainable Cities and Communities* as well as *Goal 12: Responsible Consumption and Production* (UN, 2023).

Figure 1: The 17 Sustainable Development Goals of the United Nations (UN,2023)

According to the World Green Building Council [4](WGBC), it is advised that there are a multitude of ways in which sustainability can be measured, analysed, and assessed within the built environment. These include green building design strategies, embodied energy and carbon in material and construction method selection, bioclimatic suitability of technologies, and building lifetime energy performance analysis (World Green Building Council, n.d.).

[4] World Green Building Council is a non-profit organisation responsible for regulating the rating tools used to measure a building's sustainability (World Green Building Council, n.d.).

Currently at an international level, the most practiced method of reviewing a construction project's eco-consciousness is through the building's Life Cycle Assessment [5](LCA) (Souza, 2021). The total impact of a building material or system on the environment is broken down to an analysis of each step in the process (depicted in Figure 2) of making the material or system in question (Milne & Reardon, n.d). The international standards regarding the protocol for a LCA is dictated by the International Organisation for Standardisation (ISO): ISO 14040-14044:2006[6] (ISO, 2022).

Within the context of South Africa, there are currently only a few recognised mechanisms that manage the requirements and guidelines for green [7]buildings, namely:

- The Green Building Council of South Africa (GBCSA) which makes use of the Excellence in Design for Greater Efficiencies (EDGE), Energy Water Performance (EWP), Green Star, and Net Zero rating systems.
- National Building Regulations (NBR) and Building Standards which utilises SANS 10400-XA: Energy Usage in Buildings to measure ventilation and fenestration amongst other aspects that would impact a building's operational energy performance.

Further analysis of these national guidelines in relation to other international standards highlights two distinct phases of energy usage within a building's lifecycle – the embodied[8] and operational energy[9] and carbon of a building which can be broken down into and investigated at different types of stages: cradle-to-gate, cradle-to-site, and cradle-to-grave as shown in Figure 2 (Gamazaychikov, 2021).

[5] Life Cycle Assessment – A methodical analysis of a project or product's environmental impact across its full life cycle (Kittelberger: Sphera, 2020).

[6] ISO 14040:2006 environmental management – life cycle assessment – principles and framework (ISO, 2022).

[7] Green building – A building that optimises resource utilisation whilst reduces its inherent ecological footprint and thus its impact on the environment through various facets such as embodied energy, operational energy consumption, and carbon emission (GBCSA, 2022).

[8] Embodied Energy – The amount of energy required to manufacture a building material (Metcalf,2020).

[9] Operational Energy – The amount of energy utilised to heat, cool, power, or ventilate a building during its occupational lifetime (Metcalf, 2020).

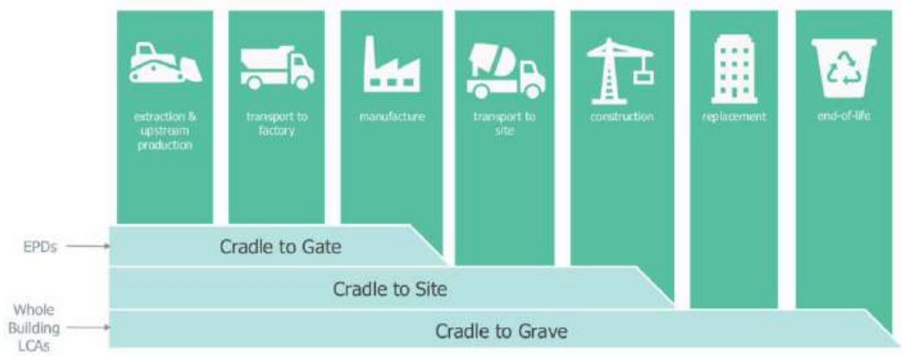


Figure 2: Tracing Embodied Carbon (Gamazaychikov: SolidGreen, 2021)

During a webinar in 2021, Boris Gamazaychikov, a carbon engineer from Stok explained that an average of 88% of a building's embodied carbon is produced during the cradle-to-gate stage of a building's lifecycle (see Figure 2) (Gamazaychikov, 2021). This percentage of carbon content at the conception, design and material manufacturing stage of a building's lifetime has a critical role to play in reducing the overall carbon footprint produced by the built environment. More informed decisions and actions must be taken to ensure proper measures are taken at each stage of a building's life to reduce the long-term impact on the environment without jeopardising adequate and safe development.

In South Africa, the criteria set out by the GBCSA and NBR stipulate building efficiencies at various phases in a building's lifetime, with strong focus placed on the operational energy consumed for it to function adequately during its time of occupation. However, current standards have a limited set of guidelines regarding the impact of the energy in materials and construction systems used in the building's assembly. The Green Star system managed by the GBCSA only considers a small portion of its overall certification criteria to the inputs of a specific building system (GBCSA, 2023). Therefore, an accurate, holistic indication of the environmental impact of a building's entirety is limited mainly to its operational lifespan.

On a larger scale, where one is to consider the overall life cycle of a building (cradle-to-grave[10]) the researcher understands that there is the potential to utilise a mixture of these recognised systems, both international and national, for green building regulations to comparatively investigate the appropriateness of IBTs verses conventional building methods in addressing the rapid need for the

[10] Cradle to Grave – From the material production to the time of the building's decommission and disposal (Gamazaychikov, 2021).

Sustainable affordable housing (SAH) – in the most environmentally sustainable manner possible (Adetooto et al, 2022).

2.5Traditional Building Techniques and the Built Environment

The built environment has an active vital role in managing sustainable human development. Currently, the construction industry contributes to approximately 12% of the indirect CO_2 emissions and 6.4% direct CO_2 emissions globally (IPCC, 2021). This exemplifies the responsibility of architecture and the building industry at large to re-evaluate the existing construction methods and materials to aid in reducing the carbon footprint of human development on the planet.

Up until now, conventional building technologies such as masonry construction, concrete and steel frame construction have been the focus of the industry. However, with the global shift towards more ecologically/environmentally sustainable human growth, alternative means of construction should be uncovered and mainstreamed.

As a conventional and universally acceptable building material, bricks have been used in construction since around 7000BC with little change to the manufacturing process over time (Almssad et al, 2022). Like many other countries, masonry construction in the form of clay brick and mortar is a popular building system in South Africa due to its material properties (Aniyikaiye et al, 2021). Characteristics of high compressive strength, thermal insulation, and fire resistance (Aniyikaiye: Dalkilic, 2017) make clay brick a suitable building material to adequately address the climatic requirements of South Africa.

On a socio-economic level, Adetooto wrote that buildings made of brick and mortar are more widely accepted as the standard for dwelling construction in South Africa with many end-users deeming it to be safe, and of a contemporary standard. With this, many other building material alternatives are seen as cheap housing solutions for the poorer communities, leaving very little room for other socially acceptable options (Adetooto,2022). Therefore, the public perception becomes critical in a construction method's overall success in the building industry.

Despite its versatile use and inherent qualities, the production of clay bricks on a large-scale account for high quantities of atmospheric pollution due to the burning of coal and other fuels during the firing process of manufacturing, thus contributing to the overall greenhouse effect (Aniyikaiye et al, 2021).

Not only does this form of traditional construction have large implications on the environment, the cost and time required to build in brick and mortar remains high due to manufacturing methods and the in-situ nature of construction (van Wyk, 2015). Masonry construction also produces a significant amount of waste due to over-ordering quantities, on site damage and defective work requiring rework due to inadequate training and application (van Wyk, 2015).

However, despite the noted implications of clay brick construction, Aniyikaiye (et al) states that efforts are underway to replace existing techniques with new modern technology such as the Vertical Shaft Brick Kiln (VSBK) which provides higher production efficiency, better energy savings as well as a reduced impact on the environment (Aniyikaiye et al, 2021). This however only addresses one aspect of the larger issue at hand and does not account for the implications of the system's constraints once on site.

2.6Innovative Building Technologies and Agrément South Africa

To reduce the industry's carbon footprint, stakeholders at both local and international levels (such as governments, green building associations and industry professionals) within the built environment have made progress towards more sustainable alternative building materials and methods with the goal of achieving more sustainable forms of human settlement development whilst reducing the impact on the environment and future populations (UN, n.d).

At the current rate of conventional building method timelines, it will take the South African construction industry approximately 70 years to adequately address the housing backlog as previously mentioned (Adetooto et al, 2022). Therefore, there is a growing need to generate more efficient and rapid building solutions to reduce the timelines, required resources and trained labour to address the pressure for more suitable housing and associated services. This is where the potential for innovative building technologies (IBTs) comes into focus.

With these two goals in mind (reducing the carbon footprint and improving the overall efficacy of the building industry) it is the intention of investigations into alternative building systems to address both local and global issues presented by academics such as Adetooto, Ampofo-Anti and van Wyk, whose focus interplays between the two scales of human issues.

Upon further readings, the following definitions provided by various sources can summarise what ABT[11] or IBTs are as well as contextualise the relevance of these technologies within this study:

"…IBT refers to the use of materials and technologies not covered by the SANS 10400 Building Standards[12]…, and where building permission is granted for such systems, materials and technologies based on either a rational design or an Agrément Certificate." (van Wyk, 2015).

"[The term] 'Innovation' has been interpreted as any building technology which is developed, without the use of South African National Standards" (Mahachi,2019).

"ABT is any expertise, skill, knowledge, equipment, machinery or tools other than conventional ones to accelerate housing delivery without compromising the quality and durability of any erected structure" (Tshivhasa and Mbanga, 2018).

"*ABTs are also non-conventional building methodologies that use economically valuable and environmentally friendly building materials to deliver affordable houses*" (South African Housing and Infrastructure Fund, 2020).

In summary, IBT systems can be categorised as unconventional building techniques or materials that seek to provide another means of construction and do not necessarily conform to any single set of building standards.

One of the many mandates set out by the Department of Human Settlements (DHS) is to provide rapid and adequate housing solutions for the growing communities across South Africa (van Reenen, 2023). In doing so, many collaborations with the stakeholders such as the National Home Builders Registration Council (NHBRC) and the Department of Science and Innovation (DSI) to name a few, have embraced the potential of IBTs as an answer to the housing crisis.

As a regulatory body for IBT systems, Agrément South Africa's role in this bigger picture is to technically assess and certify non-standardised building methods and materials that do not comply

[11] ABT – An alternative building technology which is also known as an IBT – innovative building technology (Adetooto, 2022).

[12] South Africa's National Building Regulations (NBR) provides the minimum functional requirements of universal and mandatory guidelines for all types of buildings and structures known as SANS 10400 (SANS10400.co.za, n.d).

to the standard SANS building regulations or rational design by registered professional (Agrément, 2023). Therefore, all IBT systems implemented by the aforementioned stakeholders are carefully assessed by Agrément, registered, and provided with a certificate with strict parameters and associated training requirements.

Despite the many benefits associated with IBT systems such as prefabrication, reduced in-situ construction time, reduced material wastage, there appears to be a slow uptake in the implementation of such technologies across the built environment in South Africa. As discussed in Adetooto and Windapo's paper (Adetooto et al 2022), this can be attributed to several social barriers associated with IBTs in the current South African context. Along with a lack of access to technical information, availability and costing, many non-conventional building materials have been associated with poverty or poor quality and the preference for traditional buildings such as concrete, brick and mortar are already widely understood and accepted (Adetooto et al, 2022).

For the purpose of this study, an IBT will be defined as any innovative building system or material certified by Agrément South Africa (Conradie, 2014) and the potential contributions of IBT systems to the industry will be further investigated in terms of their prospect to improve its environmental sustainability.

2.7Summary

The background research conducted as part of the literature review section of this report has illustrated that most of the present literature regarding sustainable human development, sustainability in the built environment and innovation in building materials and technologies is covered on a global scale in terms of their overall acceptance and potential economic benefits. There is a definite gap in knowledge present for academic and professional enquiry into the aforementioned topics (environmental sustainability, social acceptance, and efficacy) in the specific context of the South African built environment.

Research efforts must strive to generate more focused, national, and regional means of assessing environmental sustainability across South Africa's construction industry. In doing so, the role of IBTs could aid in addressing the need for more sustainable forms of building and therefore illustrate the need for more industry professionals and end-users to implement innovative solutions across various appropriate building typologies.

3 OUTLINE OF STUDY

3.1 Aim of Study

The main aim of the study is to better understand the position of IBTs in aiding sustainable human settlement development in the context of South Africa. More specifically, the purpose of this paper is to identify the environmental (sustainability) implications of IBTs in comparison to conventional building systems.

3.2 Objectives

The objectives of the overall study are as follows:

- Formulate an understanding of what contributes to environmental sustainability in the built environment and assess the current condition of the built environment against this understanding.
- Identify knowledge gaps in the implementation of IBTs and suggest recommendations to address these gaps.
- Illustrate the potential for IBT systems to lower the energy required by buildings and thus reduce the carbon footprint of the construction industry on the environment.

3.3 Main question & Sub-questions

Main question of the research project under which this report resides is the following:

Can IBT's compete with conventional building techniques in terms of lower embodied energy to promote environmentally sustainable human settlement development in South Africa?

The subsequent sub-questions seek to answer several aspects of the research project main question:

a) What international and national systems and policies are present to assess the embodied energy of specific building materials and technologies?

b) How do the technical advantages of IBTs impact sustainability in the human settlements sector?

c) Is there a way the environmental impact of IBTs can be compared to that of conventional building systems?

3.4 Outcomes

The intended outcome of this investigative report is to better understand the critical role of access to information and adequate resources to improve the environmental sustainability of building practices in South Africa. If the principles of such a comparative framework can be applied to real-world scenarios, this could potentially aid professionals – contractors, architects, and developers – and government as well as end-users in making informed decisions when it comes to a building project's material and technology selection, one that is both cost effective and environmentally sustainable.

4 METHODOLOGY

4.1 Introduction

This research topic has both academic and real-world practical implications. Therefore, the research question and sub-questions require a pragmatic paradigm research approach to collect, analyse, and draw conclusions on the information gathered during this investigation.

4.2 Research Paradigm

A classification breakdown of the chosen research paradigm will aid in ascertaining the appropriate methods to undertake for this study.

4.2.1 Epistemology[13]

Due to rational nature and the close connect of this investigation to the current South African building standards and global resources pertaining to environmental sustainability and human development, the research enquiry evolves from a combination of both authoritative and logical knowledge bases (Kivunja & Kuyini, 2017) to adequately address the research question and position the study within the larger discourse identified in the background section of this report, making this a relational epistemology.

4.2.2 Ontology

Ontology is concerned with the philosophical study of reality (Kivunja & Kuyini, 2017). The ontology of this enquiry resides within the 'non-singular reality' realm. This means the research acknowledges the non-singular nature of reality and that working with a multitude of variables will result in a variety of different outcomes. For this study, the research will therefore provide self-defined limitations in the selection of methods used, to ensure a focused outcome.

4.2.3 Methodology

In order to articulate the information gathered during this study, certain delimitations must be applied based on the limitations of time, resources, and lens of this enquiry. A mixed method approach was required in which both qualitative and quantitative data was utilised. By identifying IBT manufacturers

---

[13] Epistemology refers to the manner in which an individual comes to know something and relate it to the world around them. It aids in understanding the nature of the information identified as well as how it is justified in its application (Kivunja & Kuyini, 2017).

using Agrément South Africa's database as well as professional insight along with the generation of a comparative framework, a holistic conclusions based on what was acquired could be formulated.

A combination of methods was used to answer the research questions, namely: background research (desktop studies) regarding existing literature and international precedents, questionnaires with recognised professionals in the industry, and further detailed semi-structured interviews with the identified professionals, and comparative calculations in embodied energy.

4.2.3.1 Study Limitations

- Time (duration of the study)
- Access to IBT system technical data
- Limited study respondents base

4.2.3.2 Researcher's Delimitations

- Active Agrément Certificates only
- Researcher's Delimitations
- Active Agrément Certificates only
- Multi-storey application
- Modular block system or frame and panel systems only
- Sustainability in the context of this study refers to environmental sustainability only and only in terms of embodied energy.

4.2.4 Axiology

Axiology refers to the ethics and how ethical matters are managed in a study. This research investigation has Ethical Clearance, granted by the University of Pretoria, to conduct surveys and semi-structured interviews with industry professionals under Ethics Protocol Number EBIT/57/2023 (See Annexure 2 for more information).

4.2.5 Summary

A pragmatic research paradigm ensures the workability of the research findings and allows the researcher to use a mix of methods that are best suited to adequately answer the research question and its contribution without limiting its understanding to a singular perception of reality.

It was intended with this approach to the investigation, that a new perspective was gained regarding the potential of IBT systems to support sustainability; and to better equip critical stakeholders with adequate knowledge of more efficient ways to improve the sustainability of settlement development across South Africa. By scrutinising both academic resources as well as in-practice professionals' working knowledge on the topic of environmental sustainability in the building industry, this paradigm seeks to aid in bridging the gap present in knowledge transfer between academics, manufacturers and ultimately the end users.

4.3 Structure of Data Collection

As revealed in the Introduction and Literature Review sections of this report, there appears to be a number of fundamental knowledge gaps with regards to the sustainability potential of IBT integration in the South African context. Therefore, a more thorough enquiry is required to identify the barriers exist in the uptake of IBTs in the current construction industry as well as how such barriers can be overcome.

This research is limited to investigations into the question of if and how IBT systems can provide more environmentally sustainable solutions to rapid human settlement development. Therefore, the nature of enquiry is focused the following aspects based on a mixed-method approach:

- Background research regarding what contributes to environmental sustainability as well as how it can be measured to compare IBT systems and current traditional building technologies. (Later referred to as: 4.3.1 *Desktop Studies*)
- An investigation into the existing structure of Agrément South Africa as the national database for certifying alternative technologies and what technologies are currently available and in use across the country. (4.3.2 *Surveys)*
- In-practice professionals' insight in the form of online surveys and semi-structured interviews with identified IBT manufacturers in South Africa. (4.3.3 *Interviews*)
- A series of comparative embodied energy calculations. (4.3.4 *Indicative embodied energy calculation comparisons)*

4.3.1 Desktop Studies

Background research into the current recognised building methods will aid in framing the existing state of environmental sustainability across the construction industry at both the international and national level.

As previously mentioned, further reading as to what contributes towards more environmentally sustainable building practices may lead to a better understanding and comparable criteria for what might be lacking in the current construction industry in South Africa. A desktop study of this theme may uncover potential avenues outside the scope of this report that can assist in guiding future research opportunities.

To better understand the role of IBTs in South Africa, a broader search in terms of what defines an IBT aided in contextualising the argument for more uptake in non-conventional building technologies in the advancement of more sustainable human settlement development.

For the purposes of this research, only the environmental sustainability in terms of the embodied energy of an identified building material and construction systems will be investigated and compared. Supplementary data assisted in uncovering measurable methods of comparison between building material systems (conventional and/or innovative) as well as potential gaps in academic and technical research that can be addressed in further studies.

Ultimately, the selected method for comparable calculations will be identified and discussed in the desktop studies segment and later implemented in the indicative calculation portion of the results section of this report.

4.3.2 Surveys

Surveys and semi-structured interviews with industry professionals (IBT manufacturers) were used to provide both quantitative and qualitative information pertaining to specific IBT systems presently used across South Africa. By approaching these forms of enquiry in a phased manner, the initial survey was useful in identifying further questions and gaps in knowledge that were addressed in semi-structured interviews further into the research study.

Along with the background studies as described, the current database developed by Agrément informed the identification of potential industry professionals to participate in this research enquiry. Further analysis of the database was done to identify some of the existing barriers holding back the implementation of IBTs in practice.

A brief overview of the database was investigated to contextualise the focus of the study. Along with this introduction to Agrément, the participant selection criteria for the later research enquiry was limited to Agrément certified “Walling and Building System” manufacturers only. This delimitation was set based on Ampofo-Anti’s findings that a building’s envelope system can contribute between 26-30% of the building’s total LCA energy distribution and therefore calculations based on these systems would yield the largest energy saving (therefore, improved environmental sustainability outcome) comparisons for the calculation section conducted later in this study (Ampofo-Anti, 2010).

From this database breakdown, the scope of potential participants was narrowed down to two identifiable construction systems – modular block products and frame and panel systems. This resulted in a condensed list of 93 potential manufacturers for further investigation.

A spreadsheet of the prospective study participants was compiled using the details of the registered certificate system and contact information of each manufacturer. From this, each IBT manufacturer was contacted via email requesting participation in an online Google Form survey.

Results of the initial correspondence were recorded based on the responses received and catalogued as ‘Undelivered’ if an automatic reply was received stating the email was no longer active or in use, ‘No Response’ if no email reply or further contact was received by the manufacturer and ‘Response’ if any reply was received.

The goal of communication with such participants was to gain insight into the real-world situation in which IBT companies find themselves. The intention was to obtain a better understanding of the unique technical characteristics of an IBT product in comparison to conventional building techniques as well as any potential challenges that they experience when implementing these innovative technologies in building projects.

The same survey participants were used in the semi-structured interviews conducted via Google Meets later on in the study timeline.

In accordance with the terms of the ethical clearance protocol, all participants who agreed and signed a participation form were allocated a participant ID number (Participant 1 to 8) to conserve their anonymity as the information gathered is analysed throughout the course of this report.

Because this research paper was done in collaboration with another student (Cecelia Snyman) under the supervision of Dr Coralie van Reenen for the larger research theme titled: “The Role of Alternative

Building Technologies in Sustainable Human Settlements", not all questions listed in the respective annexures are relevant to this report's outcome. Therefore, the results and discussions that follow are based on this report's specific research question only.

The survey comprised of 22 questions and are available in Appendix 4: IBT Manufacturer online survey questions. The survey was administered electronically to all contacts in the database. These questions aimed to find out more specific technical information about an identified manufacturer's specific product or system as well as opinions regarding the general perception of IBTs in the industry.

4.3.3 Semi-structured Interviews

The semi-structured interviews comprised of 16 questions (Refer to Appendix 5: IBT Manufacturer semi-structured interview questions) which were issued to the participants prior to the live interview for discussion preparation purposes. These aimed to find out additional information that was unclear or incomplete based on the initial responses received by the online survey such as access to technical construction details, datasheets and reasonings behind certain qualitative answers regarding the in-practice challenges experienced.

4.3.4 Indicative embodied energy calculation comparisons

For the purposes of this study, an indicative scenario of a simple double-storey residential dwelling was used to illustrate the comparable building systems' embodied energy against a control – a traditional building system of brick and mortar.

Further delimitation was made by selecting a single IBT system type to compare against conventional masonry construction as an example of how a notional calculation comparison can be carried out to answer the research question regarding improved environmental sustainability between traditional and non-conventional building systems. The IBT type was selected based on the following criteria:

The system must closely resemble brick and mortar construction methods (ie a modular block stacking method).

The IBT type should have some similarities in material composition to conventional masonry construction.

By using a standardised form of measurement to compare various traditional and non-conventional building technologies, such as a set range of embodied energy values attributed to specific material compositions (measured in MJ/kg), the calculations intended to provide an accessible and comparable framework upon which the benefits and disadvantages of using IBTs can be clearly discerned and reviewed for a holistic conclusion to the argument at hand.

It is however worth noting that this calculation exercise is only an indicative example of how conventional and IBT building techniques can be compared and in no way does it represent an accurate and comprehensive set of values however this can be better investigated through future studies. Further research by industry professionals must be undertaken to provide scientifically accurate values for the holistic systems investigated in this report.

4.4 Data Collection and Analysis Methodology

As information was collected via each method taken, it was recorded, cross-referenced, and analysed to formulate observations, discussion, and conclusion to the study.

4.4.1 Recording Data

Research obtained through the desktop studies was collected by the researcher and kept on file for future reference in the form of hard and soft copies as well as referenced (Harvard Referencing) using the application Zotero.

The compiled list of potential study participants gathered from the Agrément Active Certificate database was recorded in a Google Sheet spreadsheet. This document lists the name of the IBT system, the manufacturing company name, contact information, the type of walling or building system as well as their Agrément Certificate number.

As replies were received by participants, their responses were updated and recorded on the same spreadsheet. A short list of candidates for the survey and semi-structured interviews was therefore discerned from the list as a whole and further communications were made.

All correspondence through emails, responses to the online Google Form survey and semi-structured interviews were recorded (voice recording and written notes included), downloaded in an acceptable format, and securely stored as part of the raw data section of this research study.

4.4.2 Cross-referencing

Due to the use of mixed methods, cross-referencing using keywords and concepts was utilised to navigate and link the various sources of information and data gathering during the study.

4.4.3 Observations

The identification of gaps or existing limitations in the use of IBTs in South Africa in terms of environmental sustainability were imperative to compiling a conclusion to the research. Along with the identified barriers in access to information, observations regarding the relationships or connections between points of interest and the research topic could aid in proposals for further enquiry and preliminary solutions to the research question.

4.4.4 Conclusion

In conclusion to this section, the inclusion of a cross-method and cross-disciplinary approach hopes to provide the study with a holistic, multi-dimensional response to the research topic at hand whilst making room for future arguments to unfold and be explored in further detail.

5 RESEARCH REPORT & RESULTS

The results obtained during this research investigation have been broken down into sections pertaining to the mixed research methods utilised. Observations can therefore be better synthesised across these methods and form part of the discussion section of this report.

5.1 Desktop Studies

As discussed in the Section 2, the literature review portion of this report, up until now the focus of improving the overall energy consumed in a building's lifecycle has been on efforts to reduce operational energy during the building's occupational running time (Ampofo-Anti, 2010). However, this has a single-sided outcome in which the interventions applied can only account for 80-90% of the total life cycle energy in a building, leaving approximately 10-20% of the remaining energy usage to chance (Ampofo-Anti, 2010).

5.1.1 Embodied Energy

Embodied energy is defined as "*a consolidation of all the energy consumed during the production of a building*" (Milne & Reardon, n.d). This value accounts for the extraction, manufacturing and transportation of the end products utilised during construction as shown in Figure 3. However, It does not include the energy associated with operating the building during its occupational phase as well as the disassembly or disposal of the building at the end of its lifetime -referred to as the *operational energy*. Because operational energy is largely dependent on how a user occupies the building (Ampofo-Anti, 2010), this study is limited to factual based information - empirical data provided by standardised measures of embodied energy present in building materials that form part of the construction period.

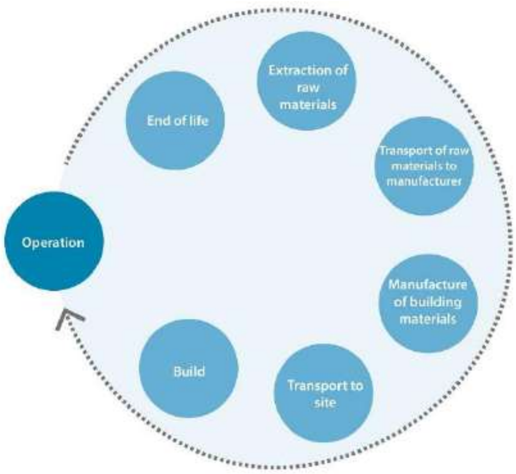


Figure 3: Diagram depicting the average life cycle stages of a building from cradle to cradle. (Souza, 2021)

Embodied energy (EE) can also be broken down into three different categories according to Ampofo-Anti's writings (Ampofo-Anti, 2010):

- Initial embodied energy: The total energy contained in all a building's materials during its construction.
- Recurring embodied energy: The total energy consumed in a building's maintenance and upkeep.
- Demolition embodied energy: The total energy required to demolish or disassemble a building at the end of its life.

A building's initial embodied energy can be further characterised by direct or indirect embodied energy. Direct EE is the energy consumed during the physical construction and indirect EE is a representation of the energy consumed in producing all the required building materials (Cole 1998).

Different construction types produce specific amounts of embodied energy; therefore, the selection of a construction technique, material or technology is vital to reducing the amount of embodied energy in the resulting building.

The extent of this enquiry is to further understand and examine the initial embodied energy of a hypothetical building scenario for comparative purposes as described in the methodology section of this report.

Further background research uncovered the following international measuring tools that assist in calculating stages of a building's LCA:
Embodied Carbon in Construction Calculator (EC3) Tool
University of Bath in the UK has a list of the energy content of common building materials.
Australian list of embodied energy content found in materials (CSIRO)

As mentioned in the introduction of this paper, in South Africa the GBCSA promotes the use of green efficiency tools that mainly focus on energy saving interventions during the building's operational lifetime such as The Green Star rating system (GBCSA, n.d). However, there is one tool that takes a more thorough look at multiple facets of a building's resource consumption, the EDGE tool by the International Finance Corporation (IFC).

The 'Excellence in Design for Greater Efficiencies' (EDGE) tool is a free to use software available online to the general public. In this format it is an invitation to industry stakeholders as an opportunity to input their project information into an online algorithmic framework in order to gain a better understanding of their building's energy and water usage throughout its lifetime. (EDGE, n.d)

Based on the international GaBi database by Sphera, the EDGE tool accesses thousands of material composition energy (and carbon) values associated with their respective manufacturing processes and use in buildings. As of 2022, 24 projects of varying scale and typology have been successfully completed in South Africa through this measurable information assessment tool (EDGE, n.d).

Computing the energy content per square meter of a building can be easier than looking at the individual energy content of each material in a building system. However, this requires an extensive database of standard values of certain building assemblies to adequately calculate and compare the embodied energy across comparable building systems (Crawford & Hall, 2020). This approach is further emphasised by Trusty and Horst in Ampofo-Anti's research, stating that comparisons between buildings must be in the context of the building system as a whole, rather than by its individual components (Ampofo-Anti, 2010).

For the purposes of this research, the environmental sustainability in terms of the embodied energy of the identified building material and construction systems will be investigated and compared using the existing facilities offered by the EDGE tool as previously discussed.

5.1.2 Traditional Building Systems in South Africa

For the intention of this study, conventional clay brick masonry construction was identified as a 'traditional building system' for comparative purposes to IBT systems identified in later sections of the report.

5.1.3 Innovative Building Technologies and Agrément South Africa

As an entity of the National Department of Public Works and Infrastructure (NDPWI), Agrément is the only national certification body for IBT systems in South Africa. This means that all non-standardised building materials and construction techniques that do not comply with SANS 10400 deem to satisfy or 'per rational design' by a competent professional during building plan approval must be tested, quality assured and certified by Agrément (Agrément, 1969).

According to Agrément's online database, there are currently 247 active certificates. Of these 247 certificate holders the most common registered certificate categories are wall and building systems with 90 certificates, wall coating systems (19), products (18), sanitation products (17), bridge deck joint systems (12) as well as 11 certificates for building systems (See Figure 4 for breakdown) (Agrément, 2023). As discussed in the methodology section, the group of potential study participants was limited to wall and building systems only.

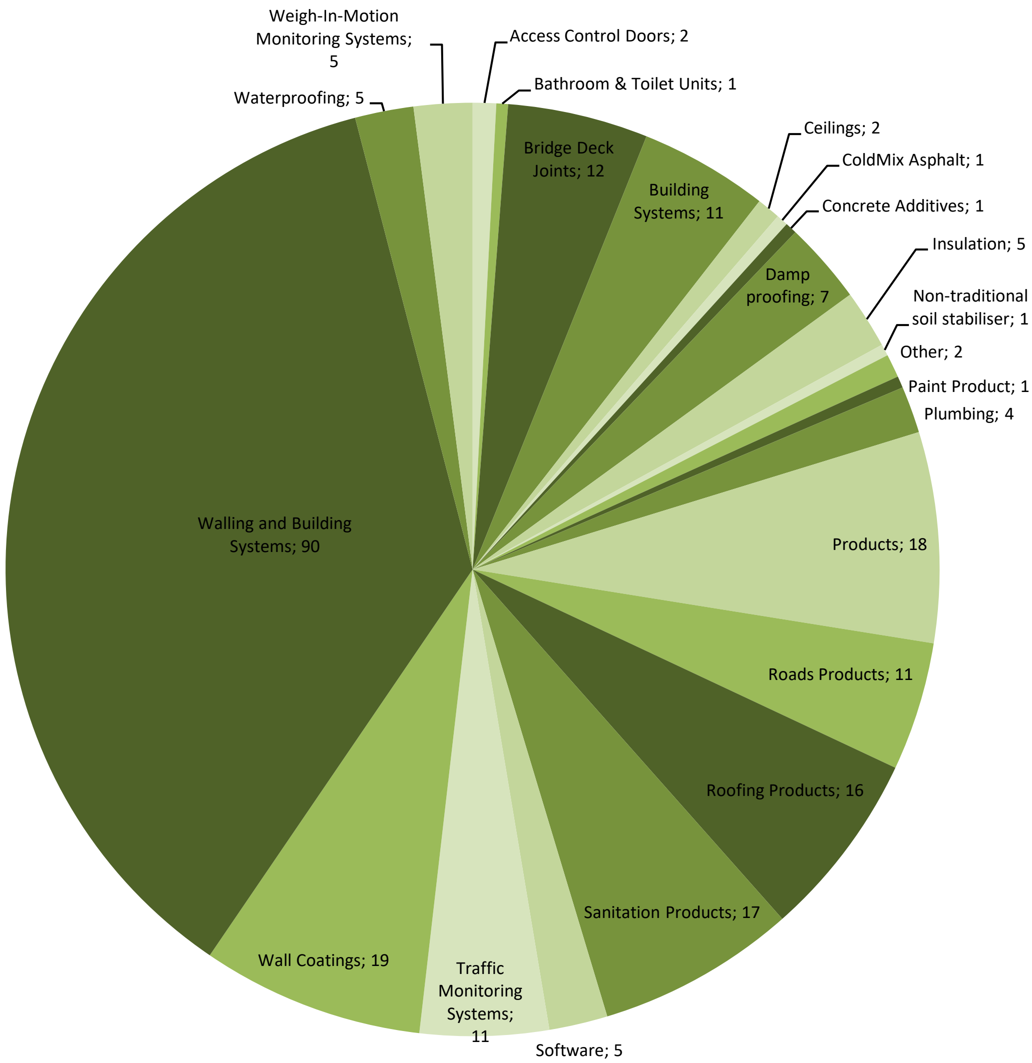


Figure 4: Agrément Active Certificates Database breakdown (By Author: Agrément, 2023)

The following sections will discuss a summary of the responses received via the online survey and semi-structured interview platforms.

5.2 Surveys

With reference to Figure 4 and , of the 93 manufacturers of walling and building systems identified, 43 had no responses to the communications sent out, 37 emails returned undelivered or invalid and

13 manufacturers responded to the content of the initial email. This process was conducted over three weeks, in which a follow up email was sent out one week after the initial email was sent and a further follow up mail issued an additional week later. It was then decided to refrain from further efforts to contact those who did not respond and record the results as such.

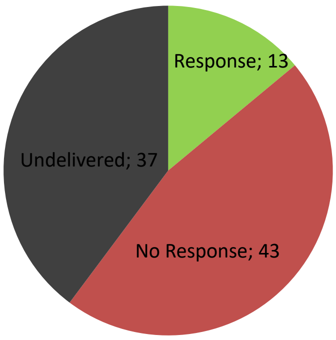


Figure 5: IBT Manufacturers' Correspondence (Author, 2023)

From the 13 replies received via email, 5 of the identified IBT manufacturers indicated that they would prefer not to participate and 8 responded yes to participating and completed the Google Form titled: *IBT Manufacturers Survey*[15].

All 8 identified respondents completed the online survey and 5 of the same participants followed up with the additional semi-structured interview process.

As previously noted, some of the questions in the Google Form survey are not pertinent to this specific report. Therefore, only the questions aimed at this report's research question will be considered, reviewed, and discussed. For access to the survey in its entirety, refer to Appendix 4: IBT Manufacturer online survey questions. It is the intention of the survey responses to gain an understanding of the barriers and challenges of the current environment from the perspective of IBT manufacturers.

A tabulated set of responses from the survey questions regarding the IBT product or system can be seen in Table 1. This summary covers the following questions in the survey:
Question 9: What occupancy class is your product/system certified for?
Question 10: How many storeys is your system certified for?
Question 12: Which category best describes your product?
Question 13: How many projects have used your system in the last 5 years?

Participant ID Code	Type of System	Certified Occupation Classes (SANS 10400) *Refer to Appendix 1 for detail	Certified Number of Storeys	No. of projects completed within the past 5 years
1	Modular Block	A1, A2, A3, A4, B3, C1, C2, D2, D3, D4, E1, E2, E3, E4, F1, F2, F3, G1, H1, H2, H3, H4, H5, J2, J3	One storey	Numerous

[15] Refer to Appendix 4 for collated survey structure.

2	Frame & Panel	A3, B2, B3, F2, E3, J2, J3, G1	Multi-storey (less than 6) depending on specific frame selected	Approximately 50
3	Frame & Panel	A3, B2, B3, D2, D3, E1, E3, F1, F2, F3, G1, H2, H3, H4	One storey	Numerous
4	Modular Block	A3, B2, B3, D2, D3, F1, F2, F3, G1, H2, H3, H4	One storey	Approximately 3
5	Frame & Panel	A3, A5, F2, G1, H2, H4	One storey	15
6	Frame & Panel	A3, G1, H2, H3, H4	One storey	4
7	Frame & Panel	A3, F2, G1, H3, H4	Dependant on rational design from Structural Engineer	5
8	Modular Block	A1, A2, A3, A4, A5, B1, B2, B3, C1, C2, D1, D2, D3, D4, E1, E2, E3, E4, F1, F2, F3, G1, H1, H2, H3, H4, H5, J1, J2, J3, J4	One storey	40

Table 1: Summary of survey results pertaining to the IBT systems' applications (Author, 2023)

Accordingly, the majority of the responses (75%) have Agrément certification for A3 – Places of Instruction, F2 – Small Shops, G1 – Offices, and H4 – Dwelling House. Of the 8 systems, 3 participants (37.5%) identified their systems as modular block products, with the remaining 5 (62.5%) identifying their IBT systems as frame and panel systems. All systems have been certified for single storey application, except for participant 2 (a frame and panel system) that can build up to six levels pending technical specification.

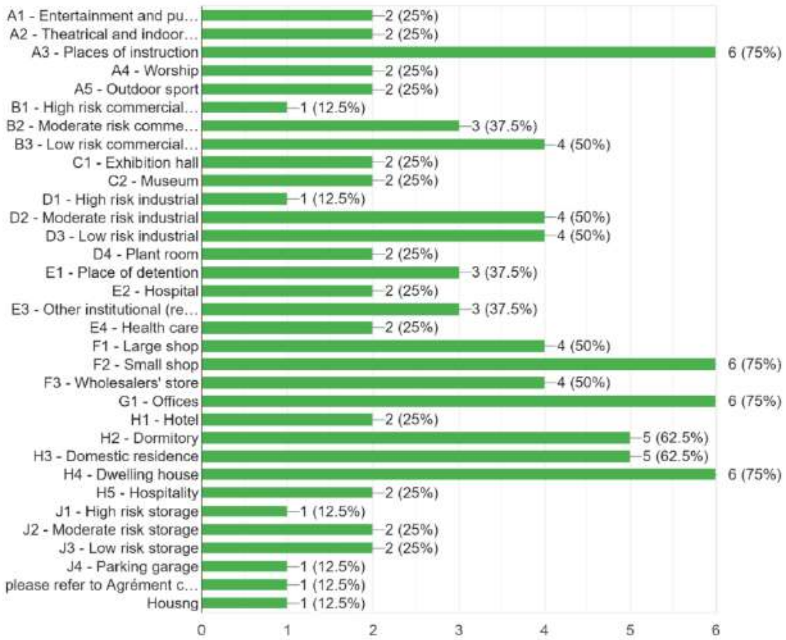


Figure 6: Screenshot of Certified Occupational Codes from SANS 10400 Part A (SANS 10400)

Survey respondents also identified some of the challenges and limitations they have experienced when working with IBT systems and Agrément South Africa. A summary of responses can be seen in below to survey question 11: *What were some of the limitations experienced during the Agrément Certification process?* and question 21: *What are some of the challenges you have faced in comparison to those who use traditional building techniques?*

Limitations/challenges experienced during the Agrément certification process:	Cost of product testing Restrictive certification Cost of participating in the certification process Slow responses, invoicing, and amendment submission process Limited understanding from Agrément with regards to specific technical data of a system Product limitations Duration of certification process Most systems are limited to single-storey application certification even though structurally, it can exceed single-storey use. Qualified testing experts
Identified application limitations/challenges of IBT systems in comparison to conventional building techniques:	Maintenance Public and builders' perception of IBTs Costs compared to other systems. Contractors' reluctancy to learn new technologies and building materials. Consumers' lack of awareness of IBTs as options. Approval from local authority can be difficult and tedious. Awareness to the superior quality of IBT systems in comparison to traditional competitor. Bank loan applications limit/do not allow for construction of buildings using IBT systems. Misconception that construction time with IBTs is longer.

Table 2: Limitations identified by survey respondents (Author, 2023)

Many participants expressed that they have experienced financial challenges when working within the IBT industry and Agrément, with 77.8% referring to the high cost of product testing and a further 55.6% noting the high cost of the certificate itself. Other practical barriers were noted such as timeframes, limited effective communication and ultimately the restriction placed on the system once approved, by the limited technical know-how of a particular IBT system and expert testing involved during the certification process.

Beyond the approval process, in the building industry itself, IBT manufacturers have indicated a general reluctancy from contractors and specialists to learning new technologies, as well as a lack of awareness and poor public perception when it comes to alternative building methods when compared to masonry construction.

5.2.1 Semi-structured Interviews

Following the initial online surveys, the semi-structured interview questions sought to discuss finer details regarding the technical nature of each IBT system as well as any additional information outstanding from the survey responses. As previously mentioned, only the relevant questions to this report were captured and summarised:

Question 1: What supplementary construction systems and materials are required in tandem with the IBT system?

Question 3: Upon which climatic-response principles is the system based?

Question 7: What are the various processes of manufacturing the IBT system requires? (Machinery, outputs, by-products etc.)

Question 8: What type of transportation methods are used to get the system to site?

Question 9: Are there any limitations of the system in comparison to its conventional building-technology counterpart? (Height, spans, durability)

Question 10: What are the maintenance requirements as well as life-expectancy of the system?

Participant ID Code	Type of System	Load bearing or Infill system	Climatic Response Principles	Supplementary construction systems and materials required	System limitations	Maintenance requirements
1	Modular Block	Load bearing or infill system	Thermal mass and insulation	Concrete foundations Columns (Reinforced concrete or steel) in some instances Standard construction tools and equipment	Height Taller buildings require additional structure and support/stability	Moisture management Same maintenance requirements as that of regular brick plastered walls
2	Frame & Panel	-	-	-	-	-
3	Frame & Panel	Load bearing	-	Any foundation types. Standard construction tools and equipment	None	Requires standard re-painting every few years
4	Modular Block	Infill system	Thermal insulation	Concrete foundation Columns (Reinforced concrete or steel) Ring-beam for roof structure Ordinary masonry construction equipment	Non-load bearing Heavy weights cannot be suspended from the walls	Requires repainting every 10 years, life expectancy is like conventional brick building
5	Frame & Panel	Load bearing	Thermal insulation	Concrete foundation LSF roofing system Drywall finishing External cladding is recommended. General hand tools required	Wall height without concrete levels	Same maintenance requirements as that of regular plastered brick walls
6	Frame & Panel	Load bearing or infill system	Thermal mass, ventilation, and insulation	Concrete foundations Columns (Reinforced concrete or steel) in some instances Mobile crane and forklift for installation	Height	Same maintenance requirements as that of regular plastered brick walls
7	Frame & Panel	Infill system	Thermal mass and insulation	Conventional foundation, surface bed, trusses, roof covering and services. Conventional building tools and equipment.	Modularity	Similar life expectancy to that of conventional systems. 100 years + Standard maintenance of painting every 5 years
8	Modular Block	Load bearing or infill system	Thermal mass	Standard foundation and structural framing (where applicable) Regular building tools for brick application	Height of 5m without added supports. Cannot carry slabs.	Standard maintenance of plastered and painted walls with minimum life expectancy of 40 years.

Table 3: Summary of semi-structured interview responses (Author, 2023)

Based on the responses received, 7 of the 8 participants responded to the preparation email of questions with only 5 participants attending the scheduled online interview slots. Each interview was approximately 30 to 45 minutes where a discussion of each participants' responses was elaborated and additional sub-questions pertaining to the main prepared questions were asked by the interviewers.

Participants were also asked what their understanding was of environmental sustainability in the built environment. The following responses were captured in Table 4:

Participant ID Code	**Question 6: What is your understanding of environmental sustainability in the built environment? (Direct quote)**
1	Environmental sustainability in the built environment refers to the practice of designing, constructing, and operating buildings and infrastructure in a manner that minimizes negative environmental impacts and promotes long-term ecological balance.
2	-
3	?????
4	Buildings should be energy efficient, thereby saving energy usage to maintain pleasant working/living conditions. Building materials should preferably be made from recycled materials, or at least be recyclable by end of life cycle. Our [IBT system 4] manufacturing process has no adverse impact on the environment, unlike clay brick manufacturing where NOx, Sox, CO, and CO2 gasses are released during the burning process.
5	Env Sustainability from my understanding is that what you take out of the environment can be returned to the environment without harming it. I believe there is very few real green products. My understanding is that when we construct that we create very little or no waste material that will end up in a landfill. Planning and planning and planning and creating these lego pieces in a factory environment is the only way to create this possibility.
6	Currently, there are no sustainable methods being applied in the built environment. [IBT system 6] is 5 steps in the right direction, however, most developments (residential and commercial) are still employing non-sustainable methods and materials. In my understanding of employing sustainable methods and materials, we have to ensure that we use recyclable and renewable materials. Further, these materials should have no adverse effect on the environment and should contribute to reducing CO2 emissions, Also, methods and materials should contribute to better living conditions for the occupants/residents of the development, without the need for external sources of heating and cooling. In addition, all processes during manufacturing and building must have minimal wastage and shrinkage
7	Our understanding of a sustainable built environment is a product designed for longevity, flexibility, adaptability, ease of assembly, disassembly, reuse and recoverability. A product that has a low carbon foot print and consists of non-toxic materials. All to ensure a sustainably around the wellbeing and safety of people.
8	By making use of and utilising waste products in the construction industry to supply innovative new products. By making use of certain design elements to address better use of certain products, services, and design elements in buildings.

Table 4: IBT manufacturers' general understanding of environmental sustainability (Author, 2023)

Cross examination and analysis of the significance pertaining to the aforementioned results depicted in Table 1 to Table 4 will be discussed in Section 6 to formulate a conclusion.

5.3 Technical System Data and Indicative Embodied Energy Calculations

The intention of applying system data collected during background research and engagements with manufacturers to a calculation exercise is to extract the potential energy saving offered by IBTs in place of conventional masonry construction. This is all to illustrate the opportunities innovative technologies can provide across the building industry in order to improve its overall environmental sustainability.

As outlined in the methodology, the indicative embodied energy calculations conducted in this section of the report was done based on the criteria described. Thus, for the purpose of maintaining sufficient accessible comparability between an IBT and the traditional building system of brick and mortar, only the alternative modular block systems identified through the Agrément database and interaction with IBT manufacturers are considered.

A control and participants 1, 4 and 8 were identified to match these criteria, with the following technical descriptions:

Participant ID Code:	System Description:
00	The control – A standard double clay brick (manufactured off-site) and mortar walling system built on a reinforced concrete foundation. Dimensions: 110x75x220mm brick modules
01	IBT System 1: A dry stack interlocking system made of soil from site with a mixture of 7-10% cement. Blocks are made from a mobile electrical or diesel-powered block compressing machine on site in accordance with the requirements of the specific project, dried and then assembled on top of a suitable concrete foundation. Dimensions: 150/180/220x115x200-240mm interlocking block modules
04	IBT System 4: A factory produced light-weight concrete block system made from foamed cement, new or recycled expanded polystyrene beads, fly-ash, additives, and foaming agent. Blocks are laid in a stretcher bond on top of a concrete foundation slab. Dimensions: 150x1200x340mm interlocking block modules
08	IBT System 8: A light-weight composite block made of recycled polystyrene, cement, fly-ash, perlite, and fibres (prefabricated off-site) that interlocks with the adjacent blocks. Dimensions: 1200x900x90mm interlocking modules

Table 5: Technical Descriptions of Participating Walling Systems (Author, 2023)

Embodied energy calculations were done using the online EDGE software[16] and a range of comparable pre-existing material parameters as discussed in the desktop studies portion of the results.

The IBT systems represented by Participants 1, 4 and 8 have undergone the same calculation exercise as the control scenario (brick and mortar) with the following set of parameters:

100 m² two-storey stand-alone dwelling

Substructure is the same (170 mm reinforced concrete surface bed and foundation)

First floor slab is the same (170 mm suspended reinforced concrete slab, unfinished)

Floor finishes are excluded.

Same roof system (to be excluded from calculation)

Same windows and doors (to be excluded from calculation)

Along with the abovementioned parameters, the following assumptions are respected:

The building site is within a 50km radius of the IBT manufacturing plant (where applicable) and therefore transportation is negligible (Ampofo-Anti, 2010).

Only the envelope of the building (exterior walls) is altered, all other superstructure is to remain the same.

[16] Disclaimer from EDGE software: "EDGE is designed as comparative software and is not a design tool. Therefore, predicted results for energy, water and materials may vary from actuals" (app.EDGEbuildings.com, 2023).

5.3.1 Calculation Study: Instance 1 – Control

Two-storey simple dwelling comprised of a 170 mm reinforced concrete slab surface bed (unfinished) with standard ***230 mm thick solid clay brick wall plastered both sides***, 170mm suspended reinforced concrete slab on first floor level, timber frame roof construction with appropriate sheet insulation and steel roof sheeting to detail.

Figure 7 represents the floor plans of ground and first floor for a standard simple dwelling in traditional masonry construction as well as the resulting floor areas of each room to which each identified IBT system will be compared.

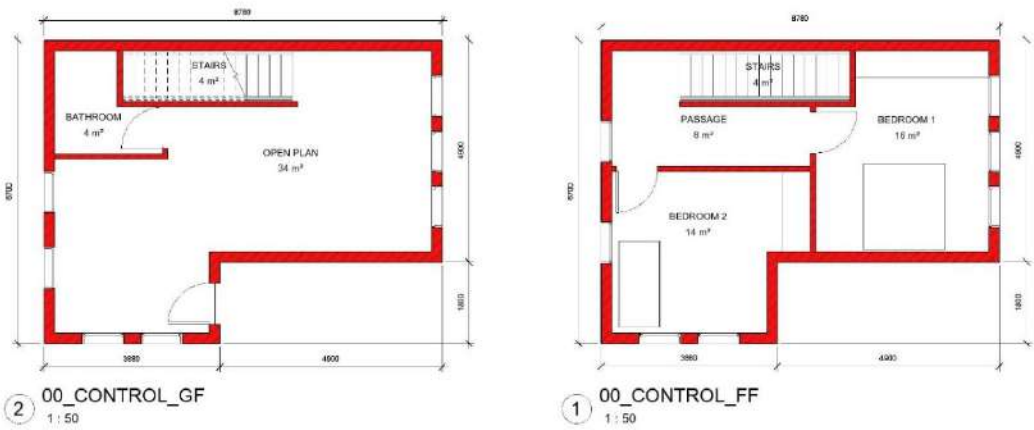


Figure 7: Ground and first floor plan of control scenario (By Author, 2023)

The EDGE tool uses a base case scenario that makes use of user-input data regarding the project's building type, location, project details, building data, areas, and overall dimensions, building HVAC systems, fuel usage and climate data (EDGE, n.d). This, along with a range of preset base case materials determined by the EDGE methodology material guide and database are used to create a baseline upon which improved cases can be measured against as one adjusts the materials selected for a particular project.

In Figure 8, a base case outcome for a typical building without any green energy-saving implementations in the region of Pretoria, South Africa can be seen on the left with the resulting embodied carbon of the building being approximately 405.92 $kgCO_2e/m^2$ (EDGE: ASHRAE, 2005). On the right is the results for the identified control scenario (a conventional double-brick masonry wall [17]as described), which has a baseline result of 416.95 $kgCO_2e/m^2$.

[17] Brick Wall: Solid brick (0-25% voids) with external and internal plaster. Thickness 230mm (EDGE,2023).

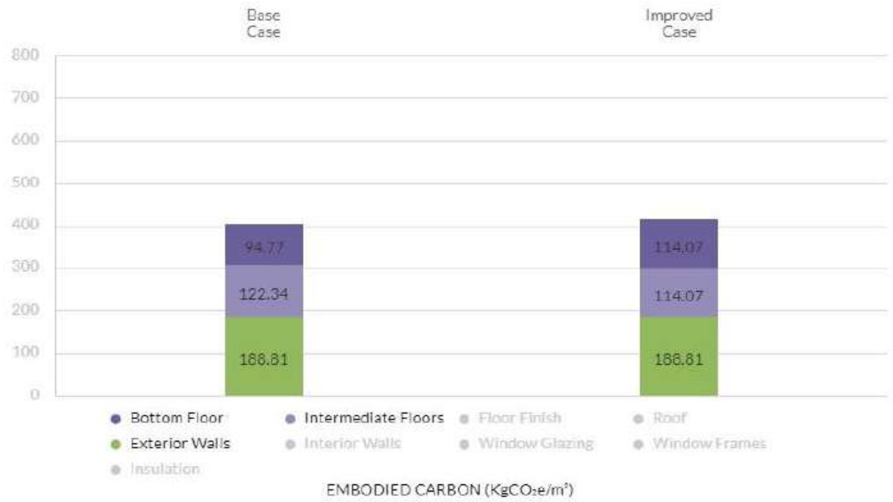


Figure 8: Material efficiency and embodied carbon - contextual base case vs study control (EDGE, 2023)

5.3.2 Calculation Study: Instance 2 – Participant 1

Two-storey simple dwelling comprised of a 170 mm reinforced concrete slab surface bed (unfinished) with ***150 mm thick compressed stabilised earth blocks no plaster***, 170 mm suspended reinforced concrete slab on first floor level, timber frame roof construction with appropriate sheet insulation and steel roof sheeting to detail.

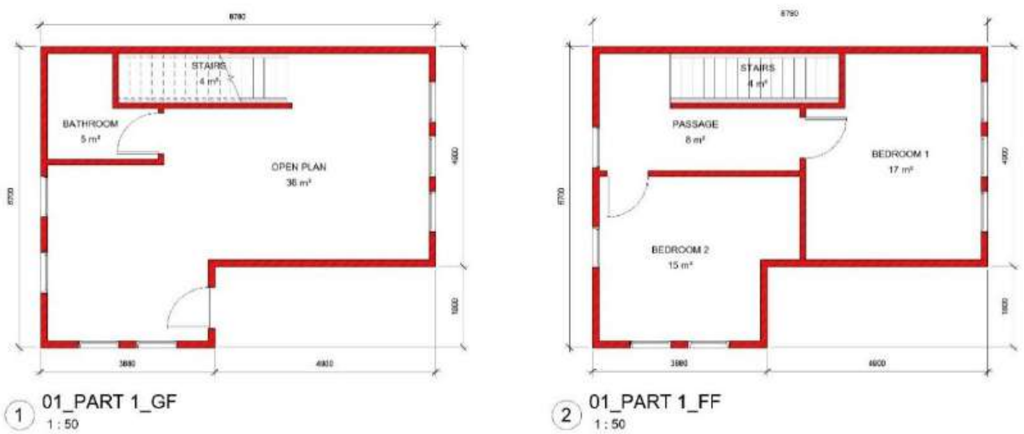


Figure 9: Ground and first floor plan of IBT system 1 scenario (By Author, 2023)

Figure 9 shows an updated floorplan of ground and first floor for a simple double-storey dwelling constructed out of IBT system 1. The external walls are thinner than the control scenario and has resulted in a larger interior floor area whilst maintaining the same external dimensions.

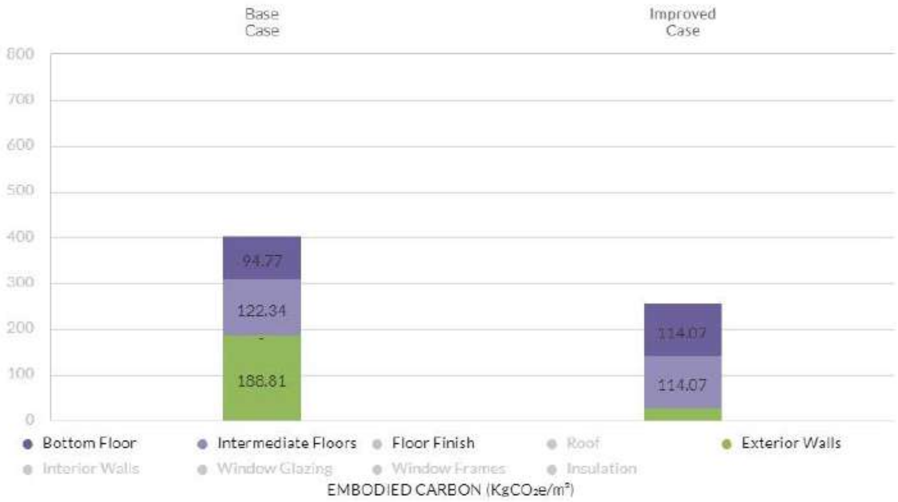


Figure 10: Material efficiency and embodied carbon - contextual base case vs IBT system 1 (EDGE, 2023)

In Figure 10, the same base case as previously mentioned can be seen on the left with the resulting embodied carbon of the building being approximately 405.92 $kgCO_2e/m^2$ (EDGE: ASHRAE, 2005). Because IBT system 1 is comprised of compressed soil from site with the addition of cement, the 'compressed stabilised earth blocks[18]' material was selected from the pre-existing list of materials available on the EDGE tool. This resulted in IBT system 1 having a total embodied carbon value of 256.56 $kgCO_2e/m^2$.

5.3.3 Calculation Study: Instance 3 – Participant 4

Two-storey simple dwelling comprised of a 170 mm reinforced concrete slab surface bed (unfinished) with 150 mm thick cellular light-weight concrete blocks no plaster, 170 mm suspended reinforced concrete slab on first floor level, timber frame roof construction with appropriate sheet insulation and steel roof sheeting to detail.

[18] Soil blocks: Compressed stabilised earth blocks. Thickness 150mm (EDGE, 2023).

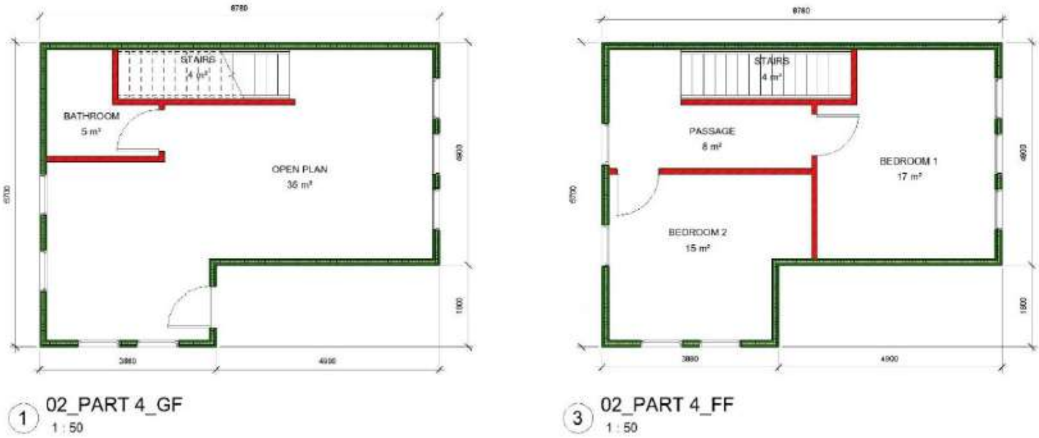


Figure 11: Ground and first floor plan of IBT system 4 scenario (By Author, 2023)

Similarly, IBT system 4 also reduced the thickness of all exterior walls from 230 mm to 150 mm therefore increasing the interior floor area as depicted in Figure 11.

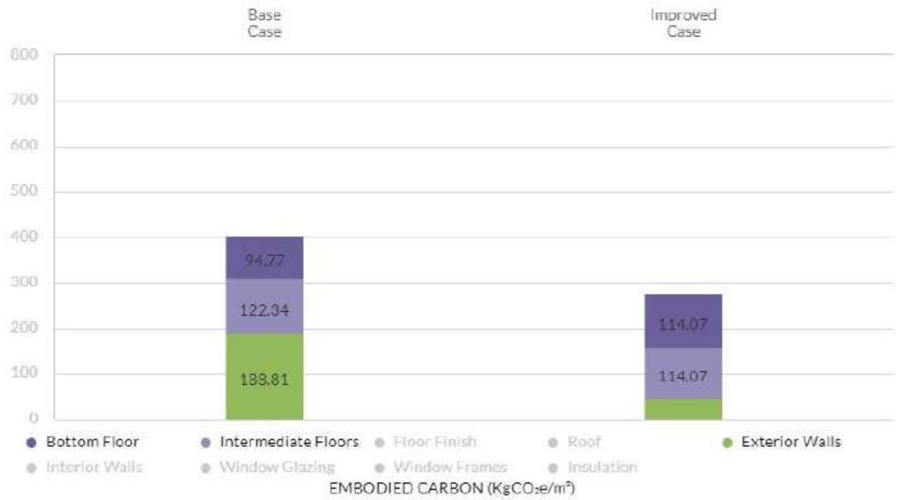


Figure 12: Material efficiency and embodied carbon - contextual base case vs IBT system 4 (EDGE, 2023)

Again, based on the technical make-up of the composite walling materials present in IBT system 4, a pre-determined material from the EDGE tool database was selected. It was found that the most comparable material was 'cellular light-weight concrete block[19]', which gave the building in IBT system 4 a total embodied carbon value of 275.23 kgCO_2e/m² (Figure 12).

[19] Concrete blocks: Cellular light-weight concrete blocks. Thickness 150mm (EDGE, 2023).

5.3.4 Calculation Study: Instance 4 – Participant 8

Two-storey simple dwelling comprised of a 170 mm reinforced concrete slab surface bed (unfinished) with 90 mm thick light-weight interlocking masonry blocks comprised of a mixture of fly-ash, slag, recycled polystyrene, cement, polymer binders; cladded in glass fibre layer with a cement plaster finish on both sides, 170 mm suspended reinforced concrete slab on first floor level, timber frame roof construction with appropriate sheet insulation and steel roof sheeting to detail.

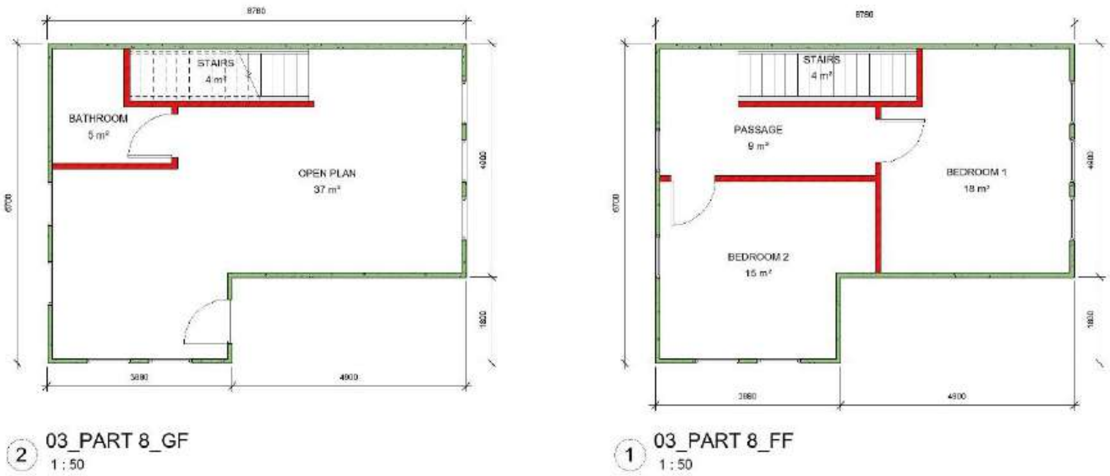


Figure 13: Ground and first floor plan of IBT system 8 scenarios (By Author, 2023)

As shown in Figure 13, IBT system 8 resulted in only a 90 mm external wall thickness thus increasing the interior floor area even more than IBT systems 1 and 4.

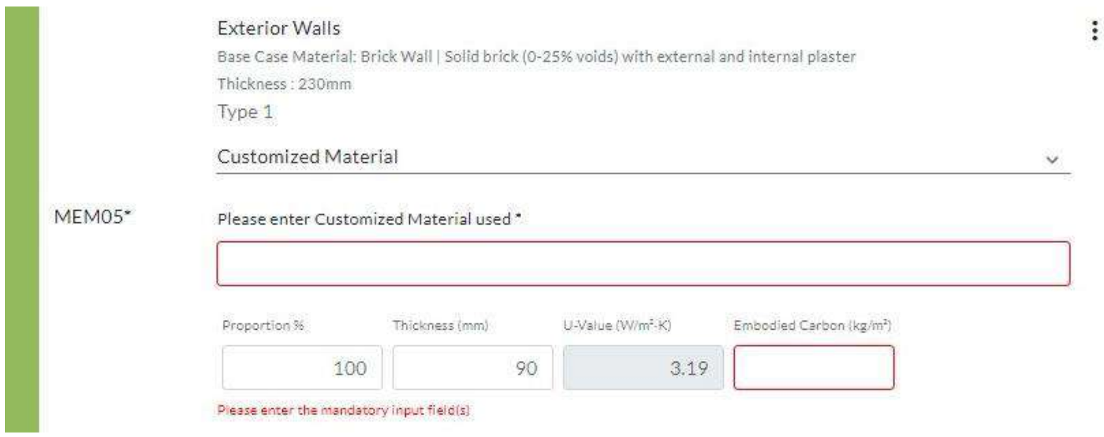


Figure 14:Material efficiency inputs table for IBT system 8 (EDGE, 2023)

Unfortunately, due to the unique composition of IBT system 8, a comparable preset was not available in the EDGE tool database (Figure 14) and therefore, a calculation comparison could not be conducted between IBT system 8 and the control. As discussed with the manufacturer during the semi-structured interview session, the company is still undergoing an LCA proposal to determine properties such as the embodied carbon of the IBT system and this information is not available at the current time.

5.4 Summary

During the results section of this report, both the background as to what embodied energy is, how it is measured and how it can be applied to comparable studies was identified and explored. Furthermore, it was identified through the surveys and interviews that majority of the presently accessible IBTs in South Africa do not have an embodied energy rating since it is not a requirement from Agrément or any regulatory body, hence the application of preset material values given by the EDGE tool.

In the following discussion section, these results and interconnected themes across the mix-methods approach will be examined to lay the foundation for analysis to better understand IBTs against conventional building systems.

6 DISCUSSION

The discussion points covered in this section pertain to a cross-referencing and amalgamation of information gathered in the introductory literature review, focused desktop studies, surveys, and interviews as well as the indicative calculations for comparative purposes. From these various sources, challenges and gaps in research will be identified and considered to tie the report together into a single, holistic conclusion.

6.1 Desktop Studies

6.1.1 A multitude of search terms

For the sake of clarity during this study, a decision had to be made to refer to the subject of non-conventional building systems as 'innovative building technologies (IBTs). However, when attempting to identify relevant academic resources pertaining to IBTs it became tedious as various names are given to the subject matter, making refined academic searches quite difficult. Therefore, part of the advance search criteria had to be expanded to include all potential search terms relating to the topic of discussion, namely alternative building technologies (ABTs), innovative building technologies (IBTs) and non-conventional building techniques/technologies. This ensured that no relevant article or resource was missed or excluded from background searches.

6.1.2 Limitations of a focused study

In the process of limiting the study to the initial embodied energy of building materials and construction methods, it becomes critical to note that this is only part of the larger picture. A much more rigorous investigation is to be conducted to understand the overall lifecycle energy consumption of a building and the implications of using IBTs on the resulting environmental sustainability.

However, choosing to focus on the embodied energy instead of the occupational energy of a building is more objective as the operational energy is largely influenced by the occupants throughout its lifetime (Milne & Reardon). This approach ensured that the information gathered by mixed sources, whether qualitative or quantitative, such as the interviews, could remain unbiased and factual in its examination.

6.1.3 Embodied energy calculations

Background research into existing methods of calculating and analysing embodied energy in building materials identified the lack of South African specific data. As mentioned, much of the national LCA practices focuses on the operational performance of building rather than the inputs into their conception and construction.

With this in mind, and in the context of IBTs, all new technologies would have to undergo the same rigorous system composition calculations in order to produce a more accurate embodied energy value for each unique product based on its material make-up.

This brings to light an opportunity for future studies and efforts towards compiling an extensive database of materials, building practices and energy consumption rates that pertain specifically to the South African context, thus equipping decision-makers with the necessary accurate data to make inherently more environmentally sustainable decisions about the industry.

6.1.4 Agrément South Africa

The poor response to communication pertaining to participating in the study, with only 13.9% responding to the initial request, could be attributed to a system that is not adequately up to date with the latest active certificates and respective contact information for IBT systems. As the only recognised platform for certified innovative technologies in South Africa, this is a critical barrier that needs to be addressed by Agrément to ensure adequate exposure of all the options available to stakeholders.

Simultaneously, better access to alternative options to the traditional building systems could grow the IBT industry and drive further innovation and funding for greener building technologies, thus better integrating these systems alongside traditionally accepted building methods. This attitude will aid in combating the backlog for housing and assist in alleviating the impact of ongoing and future urbanisation in South African cities by providing faster, cleaner, and more efficient means of building.

6.2 Surveys and Semi-structured Interviews

The use of first-hand information gathered from industry professionals via the survey and semi-structured interviews was invaluable to this study as it provided the report with a multi-dimensional set of views on the topic of IBTs in the South African construction industry.

6.2.1 The implementation of IBTs in South Africa

Many of the respondents attributed the slow uptake of IBTs in the construction industry to two major drivers: poor public perception and ineffective policy and certification practices.

In terms of perception, many IBT systems favour lightweight construction methods (62.5% according to the results illustrated in Table 1 are predominantly frame and panel systems) – which is not as familiar or widely applied in the context of South Africa. Most socially acceptable construction is based on traditional brick-and-mortar which are heavyweight systems. Some believe that this lightweight form of construction is reserved for poorer communities and does not last as long as the conventional masonry construction (van Reenen, 2023).

This highlights a lack of awareness when it comes to the technical and environmental benefits of utilising IBTs. Again, many of the respondents attributed this to ineffective system management which limit access to technical information, and promotion of innovative alternatives in the built environment.

Some interviewees also ascribed the limited application of IBT systems to restrictions placed on them by the Agrément certification itself, with many systems unable to optimally integrate into buildings because they are certified to single-storey developments only. This limitation was due to varying reasons –ranging from the high cost of certifying the system for multi-storey application as well as the limited technical know-how of the certification panel regarding a particular IBT system (Refer to Table 2: Limitations identified by survey respondents (Author, 2023). This restricts the potential environmental savings that could be performed by IBTs in South Africa, leaving little options available to promote greener, more sustainable settlement development.

6.2.2 The similarities and differences between IBT systems and conventional building technologies

As described in Table 1 and Table 3, many of the IBTs identified share similar characteristics and basic requirements, thus making the opportunity for integration of various systems easier and could lead to more versatile building solutions.

From the interviews and survey (refer to Table 1 and Table 3), several manufacturers indicated that because majority of their systems are prefabricated or manufactured off-site, little to no specialised additional equipment to the standard building tools are required, thus reducing the overall consumption of energy from the time and used of heavy machinery on site and additional skilled labour needed.

When considering the maintenance and life expectancy of IBTs (Table 3) in relation to conventional building technologies, all the interview participants indicated that their respective IBT systems require similar or even the same routine maintenance requirements as that of a standard plaster and painted brick house. If a high quality of construction work (in terms of waterproofing, plastering, and painting) are upheld on site, many of the identified IBTs can match, if not exceed the life expectancy of the conventional brick and mortar building. This principle of high quality, durable building can reduce the overall impact of a building's lifecycle on the environment and has the potential to be a driving force for greener construction practices.

6.2.3 Environmental sustainability in the built environment

As industry professionals and leaders in building innovation, all participants were asked what their understanding was of environmental sustainability in the context of the built environment (Table 4).

Generally, there was consensus amongst the responses that environmental sustainability requires careful conscious decision-making in the designing, technification and execution of construction projects. Participants emphasised terms such as 'minimise negative environmental impacts', 'promote ecological balance', and 'reduce wastage and CO_2 emissions' when defining their understanding of environmental sustainability.

These responses are interesting because there is a clear understanding from professionals with first-hand experience of the building industry in South Africa that the current construction practices are not sustainable and have a large impact in terms of energy consumption, high volumes of wastage and labour-intensive methods.

Participants also showed a well-defined sense of their role and responsibilities as leaders within the building community to continue to improve their innovations in order to lower the carbon footprint whilst maintaining production of a high standard product that improves the quality of life of the end-user (Table 4).

6.3 Technical System Data and Indicative Embodied Energy Calculations

The following discussion refers to the figures and calculations conducted in Section 5 of this report.

6.3.1 General background

As the values applied to these calculations are based on pre-determined materials, set out in the EDGE Tool's Material Methodology Guide, that are of the same or of similar nature to the identified IBTs examined in this report, the resulting embodied carbon values of each construction system's should be treated as an indicative guideline value, one that assists in informing the professional of a more environmentally considered selection of a particular building material or system in respect of another.

This method had to be applied due to the lack of South African specific datasets available with regards to embodied energy ratings for both traditional building systems as well as IBTs. This can potentially further limit the efficacy of the study because measuring environmental sustainability through material embodied energy in construction technologies is at its core, contextually specific.

As explained in the desktop study section of this report, the resulting embodied energy of a particular product is influenced by but not limited to the local availability of resources, transportation distances between the place of manufacturing and construction site as well as the type of transportation required.

This issue emphasises the importance of inter-disciplinary collaborations to develop a coherent, localised, or regionalised database with constant updates and revisions periodically that better represents the construction industry present in South Africa.

It is also critical to note that when attempting to understand the overall environmental sustainability of a building by examining the embodied energy present in its material inputs, the resulting values may vary due to several factors which require initial definition as to what to include or exclude. Depending on the project and the individual conducting the analysis, the final embodied energy value can vary by a factor of up to 10 (Milne & Reardon, n.d).

6.3.2 Indicative calculation results

For the purpose of comparison, a summarised table of the results obtained by the calculations conducted in the results section of this report can be seen below:

	EDGE Base Case	**Control**	**IBT System 1**	**IBT System 4**	**IBT System 8**
Building Component:					
Bottom floor	94.77	114.07	114.07	114.07	114.07
Intermediate floor	122.34	114.07	114.07	114.07	114.07
Exterior wall system	188.81	188.81	28.42	47.09	?

Total ($kgCO_2e/m^2$)	**405.92**	**416.95**	**256.56**	**275.23**	**?**
Total saving ($kgCO_2e/m^2$)	**-**	**-**	**160.36**	**141.75**	**?**
Total saving (%)	**-**	**-**	**38.5%**	**34.0%**	**?**

Table 6: Summarised table of calculation results (By Author, 2023)

As shown in Table 6 when comparing the quantity of embodied carbon in a standard 230mm brick house in terms of walling systems (with floor slabs remaining constant) there is a potential for approximately 34-39% energy and carbon emission reduction when applying an IBT to the same scenario. This, along with appropriate green building operational optimisation strategies could lead to further reductions in carbon footprints produced by the building industry.

Along with these observations, the use of IBT systems in place of the control also afforded more internal floor area within the same building footprint, this could potentially increase the yield of large-scale development whilst improving the overall experience of the final product by the end user by providing them with a larger home or workspace.

Another noteworthy point is the quantity of material required to produce the same building result was reduced as each IBT system was applied to the calculation exercise. The control utilised a 230mm clay brick wall system, IBT system 1 and 4 each applied a 150mm thick wall system and IBT system 8 used a 90mm thick wall system. This saving can drastically improve transportation costs and manufacturing time as less material would be required on site, further enhancing the environmental sustainability of a construction project.

Unfortunately, the potential energy savings of IBT system 8 could not be calculated due to the limited preset material list provided by the EDGE tool. A comparable or similar system for calculation purposes could not be identified and therefore it was decided to exclude IBT system 8 from the exercise. This highlights the need for a more in-depth country specific database to be created that includes both conventional forms of construction systems as well as all new IBTs as they come into being.

6.4 Summary

In summary, the information produced by this research investigation has bought to light several challenges and knowledge gaps present in the South African construction industry with the integration of IBTs. The factors hampering the use of IBTs and their potential energy saving properties as well as proposals for improvement have been discussed in this section.

6.4.1 Accessibility of information

Varying search terms to an already limited field of information makes identifying relevant academic resources pertaining to IBTs difficult to obtain. Along with this barrier is the impeded access to technical data and the available certified IBT products in South Africa due to insufficient periodic auditing of publicly accessible database information by Agrément.

6.4.2 Alternative measures for environmental sustainability

As discussed in both the introductory and desktop study sections, many mainstream measures of the environmental impact of a building's lifecycle choose to focus intervention efforts on reducing its operational energy. While this is critical to long term occupational sustainability, the initial material embodied energy implications seem to be neglected and the potential energy savings of 10-20% as described by Ampofo-Anti. There is the potential to use a more holistic approach that makes use of both the embodied and operational energy in a LCA to optimise new construction from each project inception till its end of life – in other words, a stronger cradle-to-grave and potentially cradle-to-cradle principle can be better applied to standard building practice.

6.4.3 Multi-disciplinary solutions

What the identified challenges, barriers and limitations require, in the context of IBT implementation in the South African building industry, is an ongoing cross-disciplinary engagement from a wide range of professionals such as engineers, IBT and conventional material manufacturers, quantity surveyors, academic researchers as well as designers in order to develop and maintain a relevant guide for measuring and controlling the state of environmental sustainability in the industry.

Even though mechanisms such as the GBCSA and Agrément are present in South Africa to address this matter, there is a disconnect in what should be done based on widely accepted standards and what is being implemented in the built environment. A collaborative partnership between industry leaders and various departments of government such as the DSI and DHS with research bodies such as the CSIR and University of Pretoria could bridge the gap in access to information, technical understanding and potentially promote innovation in the construction industry from the perspective of different users and stakeholders.

7 Conclusion and Recommendations

From the discussion section the following recommendations and conclusion can be made:

Better access to up-to-date information pertaining to all the available IBT systems present in South Africa is necessary to improve the general perception of alternative building technologies and ultimately address the need for rapid, clean, and adequate human settlement development that promotes environmental sustainability across the built environment.

By using an internationally recognised measure of lifecycle energy in a building, such as the EDGE tool, it can provide the framework for the development of a system or database specific to South African manufactured building materials, cost of transportation and approximate cost of labour in construction. This can then be made accessible to industry professionals and will aid designers, architects, and construction professionals to make informed environmentally sustainable decisions when it comes to the selection of building systems from the conception of a project.

With a comparable framework such as the one explored, more environmentally sustainable buildings may be produced, taking the very start of a construction project and including those critical material and construction system decisions and extrapolating their impact over the course of the building's overall lifetime. This recommendation seeks to optimise the lifecyle energy of a building from both an embodied energy and operational energy point of view.

To conclude and in answer to the research questions posed,based on the data uncovered and analysed through this research study, IBTs do indeed have the potential to better promote environmentally sustainable human settlement development in South Africa with the following points in mind:

- The reduced material quantity required by IBT systems has the potential to reduce cost and construction time on site.
- Many of the examined IBTs require limited additional specialised machinery and tools and can therefore easily be compared and measured against conventional building practices.

With the correct implementation of accurate user input and project data, measurable comparisons between different building systems (conventional or alternative) can be achieved and better-informed decisions can be made in terms of a construction project's overall environmental sustainability.

In summary, the potential for IBT systems to compete with conventional building systems within a South African setting in terms of lower embodied energy amongst other benefits is evident but further study enquiry is essential in order to facilitate a clearer transfer of knowledge between critical stakeholders in the building industry.

8 REFERENCES

2023. Certificates. *In:* INFRASTRUCTURE, P. W. A. (ed.) *Active Certificates.* Agrement South Africa.

(CAHF), C. F. A. H. F. 2022. *Dashboard: Housing and Construction in Africa: 2010-2022.* [Online]. Available: https://housingfinanceafrica.org/documents/housing-construction-africa/ [Accessed 2 April 2023].

ADAMS, M., BURROWS, V. & RICHARDSON, S. 2019. Bringing embodied carbon upfront. Available: https://buildingtransparency-live-87c7ea3ad4714-809eeaa.divio-media.com/filer_public/14/f1/14f1a27b-906d-4224-8291-a3dd1fcfae68/wc_am-bringingembodiedcarbonupfrontpdf.pdf [Accessed 13 July 2023].

AFRICA, C. F. A. H. F. I. 2022. *Housing Finance in South Africa* [Online]. Available: https://housingfinanceafrica.org/countries/south-africa/ [Accessed 2 April 2023].

ALMSSAD, A., ALMUSAED, A. & HOMOD, R. Z. 2022. Masonry in the Context of Sustainable Buildings: A Review of the Brick Role in Architecture. *Sustainability,* 14**,** 14734.

AMPOFO-ANTI, N. 2010. Material selection and embodied energy. *In:* ALIVE2GREEN (ed.) *Green building handbook.*

ANIYIKAIYE, T. E., EDOKPAYI, J. N., ODIYO, J. O. & PIKETH, S. J. 2021. Traditional Brick Making, Environmental and Socio-Economic Impacts: A Case Study of Vhembe District, South Africa. *Sustainability,* 13**,** 10659.

ARCHDAILY. 2021. *Embodied Energy in Building Materials: What it is and How to Calculate It* [Online]. Available: https://www.archdaily.com/931249/embodied-energy-in-building-materials-what-it-is-and-how-to-calculate-it [Accessed 21 May 2023].

ASDRUBALI, F., GRAZIESCHI, G., RONCONE, M., THIEBAT, F. & CARBONARO, C. 2023. Sustainability of Building Materials: Embodied Energy and Embodied Carbon of Masonry. *Energies,* 16**,** 1846.

BUCHANAN, A. H. & HONEY, B. G. 1994. Energy and carbon dioxide implications of building construction. *Energy and Buildings,* 20**,** 205-217.

BUTHELEZI, L. 2021. Johannesburg's carbon emissions a time bomb as urban sprawl continues unabated. *Business*.

COLE, R. J. 1998. Energy and greenhouse gas emissions associated with the construction of alternative structural systems. *Building and Environment,* 34**,** 335-348.

COUNCIL, W. G. B. *What is a Sustainable Built Environment?* [Online]. World Green Building Council. Available: https://worldgbc.org/what-is-a-sustainable-built-environment/ [Accessed 30 May 2023].

COUNCIL, W. G. B. 2023. *About Green Building* [Online]. Available: https://worldgbc.org/about-us/ [Accessed 14 July 2023].

CSIR, DHS & DSI, 2021. *Roadmap for Science, Technology and Innovations for Sustainable Human Settlements.* [Online] Available at: https://www.ukesa.info/library/view/sti4shs-roadmap [Accessed 8 April 2023].

CRAWFORD, R. 2020. *Embodied energy* [Online]. Available: https://www.yourhome.gov.au/materials/embodied-energy [Accessed 3 May 2023].

DIXIT, M. K. 2013. Embodied Energy Calculation: Method and Guidelines for a Building and its Constituent Materials.

DSI, 2020. *Department of Science and Innovation Strategic Plan 2020-2023* [Online] Available at: https://www.dst.gov.za/images/2020/DST_2020_2025_STRAT_PLAN_FINAL_JULY.pdf [Accessed 3 May 2023].

FORUM, C. L. 2019. Life Cycle Assessment of Buildings (LCA): A Practice Guide. Available from: https://carbonleadershipforum.org/lca-practice-guide [Accessed 7 June 2023].

FUTURE, U. N. H. F. A. B. *Urbanization in South Africa: Building inclusive & sustainable cities* [Online]. Available: https://unhabitat.org/south-africa [Accessed 15 May 2023].

GREEN, S. 2021. Embodied Carbon: Lifecycly Stages. *Solid Green Consulting* [Online]. Available from: https://www.solidgreen.co.za/lfcsa-event-embodied-carbon-of-materials/ [Accessed 13 July 2023].

HAYNES, R. 2010. Embodied Energy Calculations within Life Cycle Analysis of Residential Buildings. *Residential Buildings*.

IISD. 2023. *Sustainable Development* [Online]. Available: https://www.iisd.org/mission-and-goals/sustainable-development [Accessed 9 May 2023].

INCLUSION, U. N. D. O. E. A. S. A. S. *Social Development for Sustainable Development | DISD* [Online]. Available: https://www.un.org/development/desa/dspd/2030agenda-sdgs.html [Accessed 9 May 2023].

INSTITUE, U. L. *Embodied Carbon in Building Materials for Real Estate* [Online]. Available: https://interfaceinc.scene7.com/s7viewers/html5/eCatalogViewer.html?asset=InterfaceInc/wc_am-embodiedcarboninrealestate&config=InterfaceInc/Universal_Catalog1 [Accessed 1 June 2023].

ISO. 2006. *ISO 14040:2006* [Online]. Available: https://www.iso.org/standard/37456.html [Accessed 20 June].

KITTELBERGER, S. 2020. A Life Cycle Assessment is the systematic analysis of the environmental impact of products during their entire life cycle. *Life Cycle Assessment of a Building* [Online]. Available from: https://sphera.com/spark/life-cycle-assessment-of-a-building/ [Accessed 21 April 2023].

MAHBOOB, M., ALI, M., RASHID, T. U. & HASSAN, R. 2021. Assessment of Embodied Energy and Environmental Impact of Sustainable Building Materials and Technologies for Residential Sector. *Engineering Proceedings,* 12**,** 62.

MARZOUK, M. & ELSHABOURY, N. 2022. Science mapping analysis of embodied energy in the construction industry. *Energy Reports,* 8**,** 1362-1376.

MELBOURNE, U. O. 2023. *EPiC Database* [Online]. Available: https://msd.unimelb.edu.au/research/projects/current/environmental-performance-in-construction/epic-database [Accessed 20 June 2023].

MELTON, P. 2018. The Urgency of Embodied Carbon and What You Can Do About It [Online]. Available at: https://www.buildinggreen.com/feature/urgency-embodied-carbon-and-what-you-can-do-about-it [Accessed 3 May 2023].

METCALF, H. 2020. *Carbon zero: embodied vs operational energy* [Online]. Grand Designs Magazine. Available: https://www.granddesignsmagazine.com/self-build/zero-carbon-homes-embodied-energy-vs-operational-energy/ [Accessed 17 July 2023].

METLINK. 2020. Urban Heat Island Information. *Urban Heat Islands* [Online]. Available from: https://www.metlink.org/fieldwork-resource/urban-heat-island-introduction/ [Accessed 7 June 2023].

MORA, G. 2022. *How to Measure Embodied Energy in Building Materials* [Online]. Available: https://www.treehugger.com/embodied-energy-in-building-materials-5441578 [Accessed 21 May 2023].

NATIONS, U. 2022. *2022 Global Status Report for Buildings and Construction* [Online]. Available: http://www.unep.org/resources/publication/2022-global-status-report-buildings-and-construction [Accessed 3 April 2023].

NATIONS, U. 2022b. *The Sustainable Development Goals Report 2022* [Online]. Available: https://www.unep.org/resources/report/sustainable-development-goals-report-2022 [Accessed 13 July 2023].

OKA, T., SUZUKI, M. & KONNYA, T. 1993. The estimation of energy consumption and amount of pollutants due to the construction of buildings. *Energy and Buildings,* 19**,** 303-311.

PROGRAMME, U. N. D. 2023. *Sustainable Development Goals | United Nations Development Programme* [Online]. United Nations Development Programme. Available: https://www.undp.org/sustainable-development-goals [Accessed 5 May 2023].

REDDY, B. V. V. & JAGADISH, K. S. 2003. Embodied energy of common and alternative building materials and technologies. *Energy and Buildings,* 35**,** 129-137.

RUTLEDGE, K., MCDANIEL, M., TENG, S., HALL, H., RAMROOP, T., SPROUT, E., HUNT, J., BOUDREAU, D. & COSTA, H. 2022. *Urban Heat Island* [Online]. [Accessed 13 July 2023].

SANS. 2012. *SANS10400 Building Regulations South Africa* [Online]. Available: https://www.sans10400.co.za/ [Accessed 23 July 2023].

SHEIKH, S. E. 2022. *CO2 emissions from buildings and construction hit new high, leaving sector off track to decarbonize by 2050: UN* [Online]. Available: https://www.unep.org/news-and-stories/press-release/co2-emissions-buildings-and-construction-hit-new-high-leaving-sector [Accessed 3 April 2023].

SIMONEN, K. & KESTNER, D. 2013. Q7: *Embodied Energy vs. Embodied Carbon*. Available from: https://structureandsustainability.blogspot.com/2013/04/lca-q7-embodied-energy-vs-embodied.html [Accessed 1 June 2023].

SUSTAINABLY, B. I. 25 February 2022 2022. How do we measure the sustainability of a building? *Build It Sustainably* [Online]. Available from: https://builditsustainably.com/how-do-we-measure-the-sustainability-of-a-building/ [Accessed 15 May 2023].

TODAY, T. S. W. 2021. *What The 2021 Construction Demand Means For 2022*. Available from: https://www.tomorrowsworldtoday.com/2021/12/13/what-the-2021-construction-demand-means-for-2022/ [Accessed 23 July 2023].

URBANET. 2020. *Infographics: Urbanisation and Urban Development in South Africa* [Online]. Available: https://www.urbanet.info/infographics-urbanisation-in-south-africa/ [Accessed 15 May 2023].

VAN REENEN, C. 2023. *The role of Alternative Building Technologies in Sustainable Human Settlements.* [Research Brief] February 2023. University of Pretoria.

9 Appendices and list of annexures

Appendix 1: SANS 10400 PART A Occupancy Classes

A1	Entertainment and public assembly
A2	Theatrical and indoor sport
A3	Places of instruction
A4	Worship
A5	Outdoor sport
B1	High risk commercial service
B2	Moderate risk commercial service
B3	Low risk commercial service
C1	Exhibition hall
C2	Museum
D1	High risk industrial
D2	Moderate risk industrial
D3	Low risk industrial
D4	Plant room
E1	Place of detention
E2	Hospital
E3	Other institutional (residential)
E4	Health care
F1	Large shop
F2	Small shop
F3	Wholesalers' store
G1	Offices
H1	Hotel
H2	Dormitory
H3	Domestic residence
H4	Dwelling house
H5	Hospitality
J1	High risk storage
J2	Moderate risk storage
J3	Low risk storage
J4	Parking garage

Appendix 2: University of Pretoria Ethical Clearance Approval Letter

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Engineering, Built Environment and Information Technology

Fakulteit Ingenieurswese, Bou-omgewing en Inligtingtegnologie / Lefapha la Boetšenere, Tikologo ya Kago le Theknolotši ya Tshedimošo

21 April 2023

Reference number: EBIT/57/2023

Miss CJ Shaw
Department: Architecture
University of Pretoria
Pretoria
0083

Dear Miss CJ Shaw,

FACULTY COMMITTEE FOR RESEARCH ETHICS AND INTEGRITY

Your recent application to the EBIT Research Ethics Committee refers.

Conditional approval is granted.

This means that the research project entitled "The role of Alternative Building Technologies in Sustainable Human Settlements" is approved under the strict conditions indicated below. If these conditions are not met, approval is withdrawn automatically.

Conditions for approval:

If the respondent doesn't own the company, permission letter(s) are required.

Company's name and details are to be separated from the original data set and replaced with a code. Later these contact details need to be erased completely after the project has completed.

Reove "Upon signature of this form, the participant will be provided with a copy" as this is an online questionnaire there is no place to sign.

This approval does not imply that the researcher, student or lecturer is relieved of any accountability in terms of the Code of Ethics for Scholarly Activities of the University of Pretoria, or the Policy and Procedures for Responsible Research of the University of Pretoria. These documents are available on the website of the EBIT Ethics Committee.

If action is taken beyond the approved application, approval is withdrawn automatically.

According to the regulations, any relevant problem arising from the study or research methodology as well as any amendments or changes, must be brought to the attention of the EBIT Research Ethics Office.

The Committee must be notified on completion of the project.

The Committee wishes you every success with the research project.

Appendix 3: Permission to participate form

University of Pretoria **Masters (Professional) Architecture**

Research Project: The role of Alternative Building Technologies in Sustainable Human Settlements

Permission to Participate in Survey

I (Company Owner) _______________________________________, the undersigned, hereby consent to (Employee/Appointed Representative) __________________________________ to participate and complete the Google Form titled: "*IBT - Manufacturers*", on behalf of me, the owner of (Company Name) _________________________________.

Owner's full name & signature:

Date:

Employee/Appointed Representative's full name & signature:

Date:

Appendix 4: IBT Manufacturer online survey questions

IBT - Manufacturers

Dear Sir/Madam,

We (Cecilia Snyman and Courtney Shaw) are Master's students from the School of Architecture at the University of Pretoria, under the supervision on Dr Coralie van Reenen of the CSIR.

Our research is titled: "The role of Alternative Building Technologies in Sustainable Human Settlements"

Our study aims to identify and better understand the position of Innovative Building Technologies (IBTs) within the Built Environment of South Africa and ultimately contribute to promoting the uptake of IBTs as alternative building solutions to conventional masonry construction.

The purpose of this questionnaire is to gather information about the selected IBT system and it's relationship to the larger discourse in terms of sustainable future development across South Africa.

You were chosen as a respondent because of your company's active contributions to the development of a specific IBT system.

Your participation is voluntary and you can withdraw at any time without penalty. Throughout the survey your privacy will be protected and your participation will remain confidential. We do not wish to analyse data individually and all the data will be transferred to a computer programme to analyse the entire sample group. This means that you are assured of anonymity.

If you agree to participate, please complete the survey that follows this cover letter. It should take about 15 minutes of your time at the most. By completing the survey, you indicate that you voluntarily participate in this research. If you have any concerns, please contact our Research Supervisor with the detail provided below.

Researcher name: Dr Coralie van Reenen

Email: cvreenen@csir.co.za
We would like to thank you in advance for taking the time to answer our questions and assisting us in gathering the information necessary to complete this research investigation.

* Indicates required question

Appendix 5: IBT Manufacturer semi-structured interview questions

Thank you for your continued willingness to participate in our study and provide us with your valuable experience and knowledge in the field of IBTs.

This study aims to identify and better understand the position of Innovative Building Technologies (IBTs) within the Built Environment of South Africa and ultimately contribute to promoting the uptake of IBTs as alternative building solutions to conventional masonry construction.

Below are the questions for your consideration relating to IBT products and systems. We, MArch Students at the University of Pretoria - Cecilia Snyman and Courtney Shaw, would greatly appreciate your help in answering the following questions in as much detail as you can give. The information from these questions will prove to be extremely valuable in our continued research surrounding our study titled, ***'The role of Alternative Building Technologies in Sustainable Human Settlements**.'*

Upon the reply of these questions, we will like to schedule an in-person appointment with you to further discuss the information you have provided below.

All collected data (i.e. original dataset with perhaps identifiable information) and other related information (i.e. recordings, transcriptions) accumulated for this research study / research project will be stored in a secure storage space (i.e. electronic data or hard-copy data). Access to the original data will be limited to only team members. This enables researchers to ensure the anonymity and confidentiality of participants. De-identified datasets used for analysis will be stored on the University of Pretoria research data repository and platform (https://researchdata.up.ac.za/). The University of Pretoria manages, maintains, and controls this platform. All data stored on the mentioned platforms will be disposed of and destroyed after the prescribed period and by means of the prescribed method as defined by the University of Pretoria Information Management policy.

Questions:

1. What supplementary construction systems and materials are required in tandem with the IBT system? (i.e. existing concrete surface bed, steel or concrete frame structure, pile or strip foundations, roofing system)
   Your answer…

   a. What tools are required on site?
      Your answer…

   b. Are there specific conditions the site needs to be in to allow for effective installation?
      Your answer…

2. Could we get contact information to contractors, project managers and/or site managers to interview on implementation and the end product?
   Your answer…

3. Upon which climatic-response principles is the system based? (Thermal Mass, Ventilation, Insulation, Shading etc)
   Your answer…