Market Opportunities and Barriers to the Uptake of Low Embodied Energy Building Materials and Components: The Case of Interlocking Blocks in Johannesburg

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Declaration

I, Minenhle Yvonne Desiree Maphumulo, declare that this research report is my own unaided work. The report is submitted for the degree of Master of Urban Studies in Sustainable and Energy Efficient Cities (MUS - SEEC) to the Faculty of Engineering and the Built Environment at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

Signature of Candidate Date: September 30, 2022

Abstract

The intensifying urbanisation challenge in the global south, coupled with the resultant need for housing calls for governments to re-think how they address related needs sustainably especially due to resultant GHG-emissions and climate change. In order to decarbonise housing development for the City of Johannesburg, this study argues that, as one of the most visible alternative building materials and systems (ABMS), interlocking blocks have the potential to contribute significantly towards low carbon homes provided that critical barriers to their diffusion are systematically addressed. Guided by a qualitative study approach and focusing on an existing business in interlocking blocks as a case study, a supply-chain framework was applied to identify the relevant actors and stakeholders from whom interview participants were purposely selected and interview questions were then articulated.

Subsequent to data presentation and analyses, overall findings were articulated in terms of opportunities and barriers. In particular, the study finds that on the basis of their production and construction process, interlocking blocks confer significant benefits such as eliminating the need for conventional burnt-clay bricks which entail high embodied energy, saving on cement as a high embodied energy material as the laying of the blocks is mortarless, process of construction is significantly simplified such that low-skilled labour can be engaged, overall construction cost and time are significantly reduced thus enhancing affordability for homeowners and tenants.

On barriers, the findings further indicate inadequate guidelines and incentives towards strategic promotion of low carbon materials. Negative perception of ABMS by various actors contributes to superficial cost comparisons by clients and professionals based on building material unit prices instead of the overall outcome holistically. Such perceptions also reinforce propensity to gravitate towards conventional materials. The study therefore concludes that even though most of the socioeconomic and environmental benefits of ABMS strongly resonate with national and municipal policies and goals, their uptake will remain constrained until supportive regulations and incentives are adopted in the construction sector, especially with regard to reducing embodied energy while also facilitating innovation and green-skills in the sector.

Key words: *alternative building materials and systems, interlocking blocks, embodied energy, low carbon homes*

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Abbreviations and Acronyms

3D	Three-Dimensional
ABMS	Alternative Building Materials and Systems
ABT	Alternative Building Technologies
CIDB	Construction Industry Development Board
CMA	Concrete Manufacturers Association
CO2/ CO_2	Carbon Dioxide
CoJ	City of Joburg
CAP	Climate Action Plan
CSD	Central Supplier Database
DFFE	Department of Forestry, Fisheries and the Environment
DHS	Department of Human Settlements
EDGE	Excellence in Design for Greater Efficiencies
EE	Embodied Energy
GBM	Green Building Materials
GDP	Gross Domestic Product
GDS	Growth and Development Strategy
GHG	Green House Gases
GLA	Greater London Authority
IBT	Innovative Building Technology
IETA	International Emissions Trading Association
IFC	International Finance Corporation
IPP	Intellectual Property Protection
IP	Intellectual Property
JOSHCO	Johannesburg Social Housing Company
JPC	Johannesburg Property Company
KBB	Kavango Block Brick
LCA	Life Cycle Analysis
LED	Low Emission Development
NBR	National Building Regulations
NCCRWP	National Climate Change Response White Paper
NHBRC	National Home Builders Registration Council
POPIA	Protection of Personal Information Act
RFP	Requests for Proposals
RFQ	Requests for Quotations

SABS	South African Bureau of Standards
SANS	South African National Standards
SDP	Site Development Plans
SHS	Sustainable Human Settlements
USGBC	United States Green Building Council

CHAPTER 1: INTRODUCTION AND MOTIVATION OF THE STUDY

1.1 Introduction: Motivation and Contextualisation of the Study

The construction sector is critical for the development and growth of South Africa as it provides physical infrastructure and housing while stimulating economic activities and social development. However, it is unfortunately regarded as one of the major contributors of negative impacts on the environment due to the high levels of waste generated from building material production processes, construction methods, and renovation strategies as well as demolition (Aboginije *et al*, 2020). As efforts towards promoting the use of green building materials (GBM) and encouraging practices that contribute to a reduction in consumption of non-renewable resources in sustainable human settlements, the diffusion of green buildings in developing countries has been limited (Eze *et al*, 2021).

As a response to mitigating the impacts of climate change, low carbon development and associated GBM need to be carefully considered especially given escalating increases in the rate of construction activities aimed at accommodating the rapid urbanisation especially for cities in developing countries (Zhang and Biswas, 2021). Building materials constitute the largest construction cost component in residential developments. Consideration of more energy efficient building materials options has therefore become an important aspect for the global agenda to produce tangible outcomes and ultimately reduce carbon emissions in the construction industry (Oyebisi *et al*, 2021). With increasing initiatives towards the ultimate zero energy building, embodied energy has emerged as the next frontier in energy management and life cycle of buildings (Morini *et al*, 2019). The increasing focus on GBM is therefore in response to the urgency for global restructuring of the construction industry to make it more responsive to the resultant challenges of environmental degradation, global warming and resource depletion (Eze *et al*, 2021).

However, the diffusion of sustainable construction techniques and products face critical challenges towards incorporation and implementation. In particular, such Innovative Building Technologies (IBTs) have not been adopted in the mainstream construction market at a scale which would rival that of the conventional options, particularly in the global South.

Based on the low embodied energy of their input materials and their mortar-less assembly method for walls, interlocking blocks are viewed as one of the viable options towards low-carbon building construction. This study therefore investigates advances made in innovations for sustainable low carbon building materials and construction technology with particular focus

on dry-stacking of interlocking blocks in relation to their contribution to low-carbon residential developments.

In particular, the research aimed at evaluating the potential contribution of interlocking blocks to low-carbon residential development as well as identifying the forces hindering expedited diffusion of low-carbon IBTs in the building construction sector in South Africa with Johannesburg as the specific area of interest. Interrogation of market opportunities and challenges facing interlocking blocks is based on market experiences of *Hustlenomics* as the business case study as well as perceptions of various built environment professionals within Johannesburg.

1.2 Background

Globally, the built environment (the production of buildings as well their operation) consumes 40% of the world's energy (Morini *et al*, 2019). There is therefore a direct link between buildings and their related carbon emissions versus the ability of the natural environment to absorb carbon dioxide (USGBC, 2008). Increasing emissions and the diminishing capacity of the natural environment to absorb carbon dioxide are the key contributing factors to accumulation of Green House Gases (GHG) in the upper atmosphere (USGBC, 2008).

As shown in Figure 1, South Africa emits the highest levels of CO_2 in Africa and has one of the highest CO_2 emissions per unit of Gross Domestic Product (GDP) in the world (Ritchie *et al*, 2020). In particular, Figure 2 shows that emissions are predominantly from coal. Ritchie *et al*, (2020) also gives an expanded view which shows that the use of coal contributed to 394.05 million tonnes of CO_2 emissions followed by oil at 43.53 million tonnes while gas-related emissions were at 8.39 million tonnes and cement as the fourth largest emitter at 6.01 million tonnes in 2020.

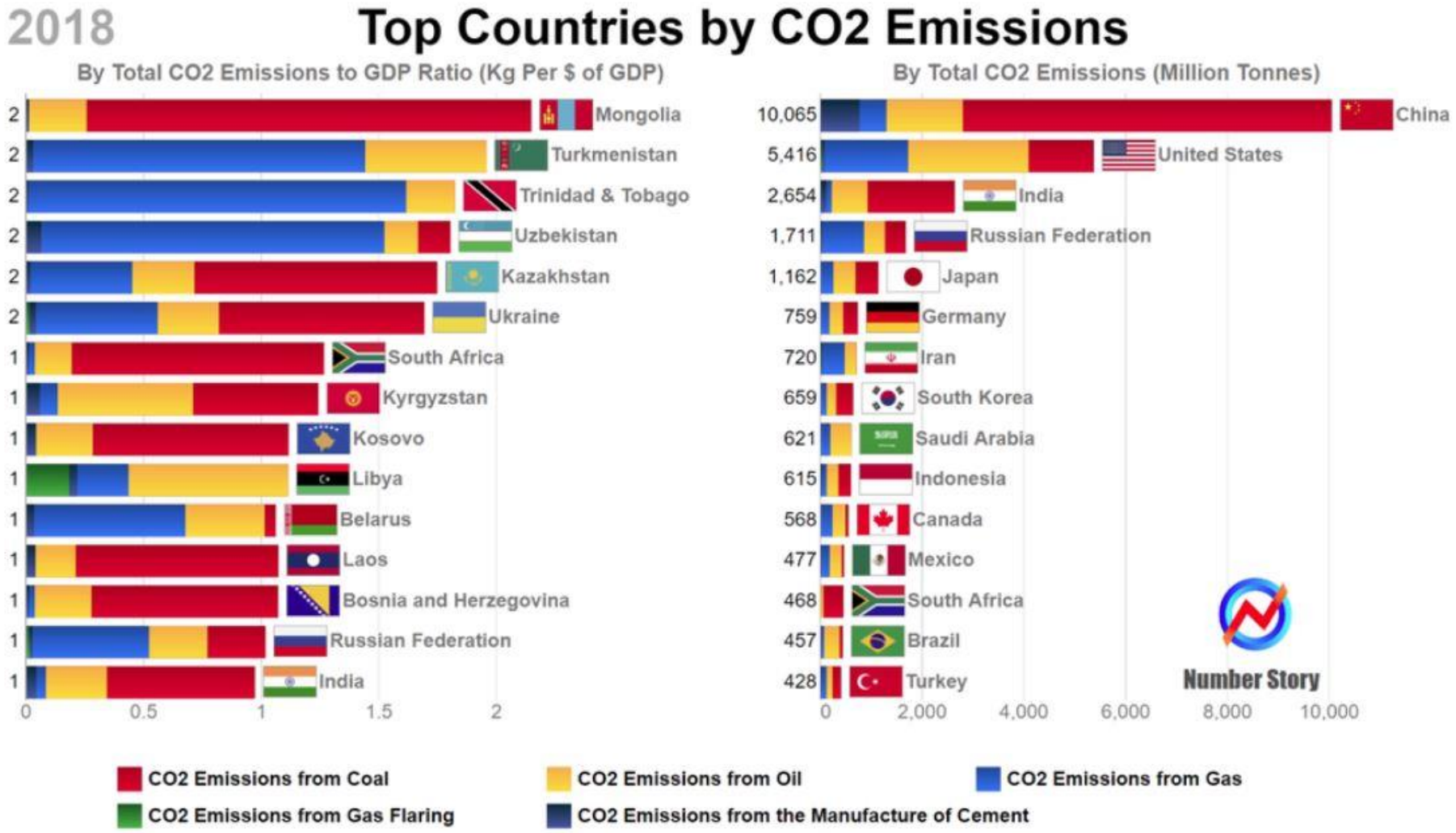

Figure 1: Top 15 countries by CO_2 emissions in 2018: by emissions and emissions to GDP. Source: (Number Story, 2020: 1)

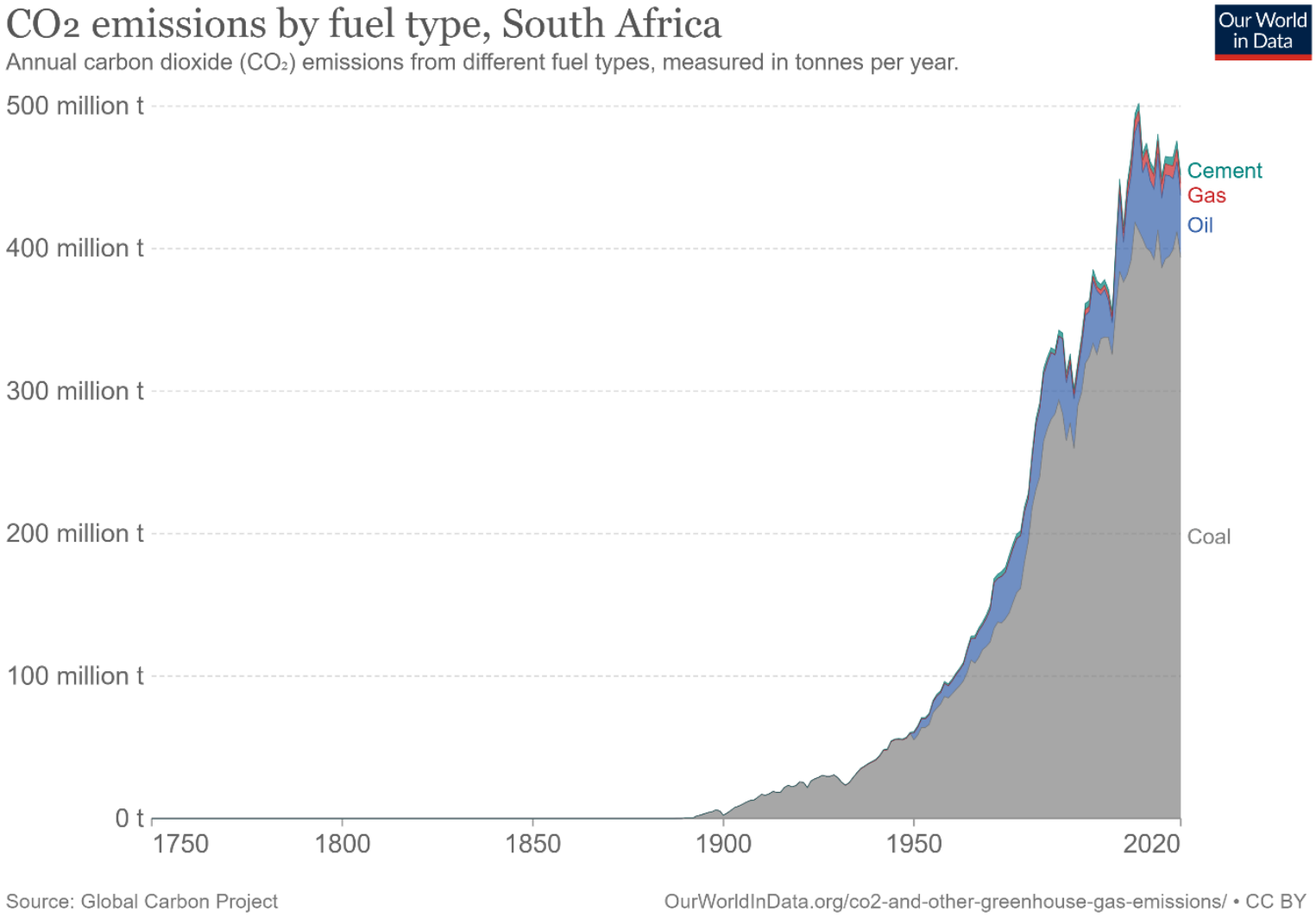

Figure 2: Annual carbon dioxide (CO_2) emissions from different fuel types, measured in tonnes per year. Source: (Ritchie et al, 2020: 1)

The data indicates that the onus for CO_2 emissions reduction mostly rests on industries that depend on the highlighted fuel types. This study cuts through all the identified fuel types which contribute, directly or indirectly, to the construction of residential development, but explicitly narrows the focus to cement which is noted as the fourth highest contributing emitter. It is mostly used as a direct input in the construction industry and thus speaks directly to the need for reduced use of cement in favour of more environmentally friendly alternatives and approaches in construction as well as more energy efficient cement production processes.

Cement manufacturing is a highly energy and emissions intensive process due to the high temperatures required for heating of limestone and for the grinding of raw materials used in its production. The preparation of raw materials typically depends on intense use of electricity, of which in the case of South Africa, is predominately coal generated (Ige and Inambao, 2021). As noted in the Figure 2 above coal is also listed as on one of the heavy CO_2 emissions fuels. This suggests that the shift away from coal generated electricity towards renewable resources has the potential to reduce CO_2 emissions due to electrical consumption (Ige and Inambao, 2021).

With increasing urbanisation, the demand for housing in many cities continues to grow. In most cities, housing comprises the largest proportion of the building stock which in turn makes it a significant contributor to energy consumption and related CO_2 emissions (Abubakar and Doan, 2017). The high ranking of CO_2 emission by the construction industry places pressure on related materials manufacturers (as the supply side of the market) to respond with carbon emission reduction strategies and interventions.

On the demand side, the concept of Embodied Energy (EE) has been articulated as the sum of indirect energy consumed in the processing and distribution of all components used during on-site assembly at construction stage (Cabeza *et al*, 2013). The energy considered is inclusive of transportation as well as energy consumed in the demolition and disposal of buildings at end of their life cycle (Cabeza *et al*, 2013). The study is therefore premised on the increasing understanding that building materials that entail high embodied energy in their production and construction stages result in more CO_2 emissions than those with low embodied energy. This argument highlights the need to focus on strategies and regulations for Alternative Building Materials and Systems (ABMS) with lower embodied energy.

Based on a techno-economic and environmental performance assessment, Zhang and Biswas (2021) argue that the replacement of conventional bricks with dry stacking of interlocking blocks improves the structural performance of walls, especially in housing. In

addition, the self-aligning dry stacking assembly method was also found to reduce construction time, labour costs and material costs. Secondly, the mortar-less method also addresses the challenges around damage due to shrinkage (Zhang and Biswas, 2021). Thirdly, their assessment revealed that interlocking block system constitutes a significant improvement from the conventional brick production process as it is based on compression without the need for firing, thus reducing the resultant carbon emissions.

Although the interlocking block method has proven to be advantageous in several ways, Adedeji (2011) argues that its use in construction is still relatively low in African cities primarily due to slow diffusion. Based on Nigerian experience, the study finds that the slow uptake was negatively influenced by low public and professional awareness of its merits together with inadequate availability in the market. Similar studies on the slow diffusion of innovative construction materials and components with proven structural and environmental performance benefits in South Africa need to be prioritised.

1.3 Rationale for the Research

In view of the unsatisfactory rate of adoption of interlocking blocks in sustainable housing development in South African cities, the primary aim of the study is to improve understanding of market opportunities and barriers to the uptake of low embodied energy building materials in South Africa with the Johannesburg context as the key focus. The study of building materials with low embodied energy also has the potential to improve building material choices and decisions made by construction sector professionals, clients, organisations and end-users mainly through demonstration of their unique technical and environmental performance. Ultimately, this would contribute towards net-zero carbon emissions goal as set out in various international and local climate change mitigation policies and strategies.

The study therefore aims to further clarify the link between levels of awareness, implementation and, most importantly, adoption and diffusion of the GBM materials in the construction industry in South Africa. Furthermore, the study also served as a learning experience towards a deeper understanding of the complex relationship between global agenda, product developers, suppliers, professionals and homeowners. It also generated new understanding of the sustainability impact (especially in terms of low-carbon goal) of material selection as set out by a variety of target based technical performance rating systems such as Excellence in Design for Greater Efficiencies (EDGE). Finally, this study contributes to the sparse body of literature on low embodied energy building materials in the built environment and construction disciplines and therefore positively informs future development choices in the construction sector.

1.4 Problem Statement

In spite of the limited growth in adoption of green construction practices and building materials, the adoption of green buildings is gradually gaining traction in South Africa's property market (Simpeh *et al*, 2020). The selection of green construction materials is a potential variable towards minimising embodied energy in development and reduction of CO_2 emissions in an effort to mitigate the escalating impacts of global climate change. This is particularly important for developing countries which are undergoing rapid urbanisation coupled with major infrastructure development which typically require enormous resources towards construction activities. Even though there is an increasing interest in GBM, one of the most notable outcomes is the low usage compared to the use of conventional materials or components (Aghimien *et al*, 2016). Some of the commonly identified challenges in relation to the low uptake of innovative materials and technologies in construction are as follows:

- **Typically marketed as an innovative option for low-cost housing developments:** Interlocking blocks are not successfully marketed as viable and adequate building components for all types of housing development in the same manner as conventional blocks or bricks
- **Cultural and social resistance:** Simpeh *et al* (2020) affirms that the South African construction industry is a highly conservative sector that does not easily adapt to changing market needs. From a Nigerian experience, Adedeji (2011) noted that the slow adoption was influenced by poor public and professional awareness as well as fear of liability over performance risk of new products
- **Inadequate cost and performance data**: In the attempt to meet escalating housing demand performance of building materials used for affordable housing is typically side-lined by narrow emphasis on cost-reduction coupled with limited life cycle analysis on how such materials and construction technologies impact on operational costs. This results in highly inefficient buildings at occupation/operation stage as well as total disregard of related environmental impacts
- **Poor competition in terms of machinery producers:** The range of actors in the production of machinery for making interlocking blocks in South Africa appears to be extremely limited. One of the leading providers in the southern African market is Hydraform which is linked to the business case study of the reported research
- **Lack of institutional support and incentives:** Support in the form of incentives not only inspire and encourage practitioners and professionals to do better but also improves awareness which help expand the green building sub-sector. Simpeh *et al* (2020) affirms that there is limited reward for demonstrating best green practice in South Africa's construction industry

1.5 Objectives

Existing literature suggests that both the production process of interlocking blocks and mortar-less building practice offer more carbon-conscious routes than conventional bricks. Building on that, the study assessed the role that ecologically friendly materials and the production thereof can play in the provision of low-carbon housing in the Johannesburg context. The reduction of embodied energy in buildings can help reduce carbon emission as well as encourage more energy efficiency in the provision of housing. The secondary objective was to identify the key factors that contribute to the low levels of diffusion of low-carbon building materials and especially for materials geared towards dry stacking. The study therefore identifies the inadequate availability of interlocking blocks in the mainstream market and limited engagement with built environment professionals as well as end-users as the key limitations which contribute to inadequate diffusion.

1.6 Main Research Question and Sub-questions

In view of the rationale and objectives of the study, the main research question was conceptualised as follows:

> **How could the diffusion of interlocking masonry blocks be accelerated towards facilitating the provision of low-carbon sustainable human settlements in Johannesburg?**

For purposes of formulating data collection and analyses tools, the research question was structured into the following sub-questions:

- What are the critical perceptions on interlocking blocks in the Johannesburg housing construction market?
- How do interlocking blocks contribute to the agenda for reducing low embodied energy in housing construction compared to conventional bricks?
- What are the key barriers to the diffusion of interlocking blocks in the residential development sub-sector of the construction industry?
- How can the perceptions and barriers be addressed in order to enhance the uptake of innovative sustainable building materials?

1.7 Definition of Key Concepts

- Alternative Building Materials and Systems (ABMS) – is a generic term used to describe a class of building materials and their related building systems normally considered to fall outside of conventional materials in the market. ABMS may also be interchangeably be referred to as unconventional building materials, sustainable building materials, environmentally responsible building materials

- Embodied Energy (EE) – Abey and Kolathayar (2020) defines EE as the total energy consumption linked with a product or system inclusive of extraction, processing, transportation, placement, maintenance and disposal after end of life

- Green Building Materials (GBM) – denote materials that are environmentally sensitive but still offer high performance and energy efficiency

- Innovative Building Technologies (IBTs) – any form of building systems, methods, materials elements or components which are still in their product-development phase and are therefore not yet fully covered under existing standards and specifications or codes of practice (NHBRC, 2020)

1.8 Working Hypothesis Based On Overall Research Question

The envisaged resolution of the study is that the gap in the uptake of interlocking blocks and other IBTs is related to unfulfilled market opportunities in the green economy and related barriers. The working hypothesis of the study is that an increased uptake may be seen when market-oriented initiatives aimed at increasing the awareness of the benefits associated with the use of green building materials are supported. Market- oriented initiatives are also needed in order to mitigate on existing obstacles that limit the uptake and overall growth of innovative low carbon construction technologies.

1.9 Delimitation of Scope of the Study

The study aims to explore the potential use of low carbon building materials and components within the residential property market of the City of Johannesburg and its potential towards GHG emissions reduction. As a result, findings of the study are specific to the context of Johannesburg such that similar studies in other city contexts are likely to yield different findings. Methodological and geographic limitation means that the findings of the study might not be directly transferable to other contexts. In the same vein, while the experience in Johannesburg may be useful for other African cities, the contextual settings and framework may challenge the application of the lessons learnt in another city. In the pursuit of examining

the role of interlocking blocks and dry stacking, some of the findings were derived on the basis of secondary data where generalizability of the reported study findings would be subject to certain limitations. Another limitation anticipated is that the production of interlocking blocks is heavily dependent on the availability of the right soils which would be influenced by local geological conditions. This also suggests that in different contexts, uptake enhancement strategies may still be impended by factors beyond the market-oriented initiatives prioritised in the study.

Recent construction related studies suggest a growing trend towards automated systems at research and development phase from hydraulic excavations and bulldozers to concrete 3D printing and interlocking blocks, but very limited uptake in the market (Hossain *et al*, 2020). Automation of construction equipment is said to have the potential of accelerating productivity, reduce material costs and minimise risk. Although the research report recognises three-dimensional (3D) printing among some of the innovative construction technologies compared to conventional methods, it falls outside the scope of this study.

Three-dimensional (3D) printing is a digital innovation used to fabricate specific objects, components or structures directly from their respective digital models. The process uses modelling software such as Revit to create an object through incremental layering. Allouzi *et al* (2020) reviewed advances in 3D printing construction with concrete in Jordan as a developing country facing a serious housing crisis due to refugees currently living in make-shift camps. The review reflects on the experience of using 3D printing for the construction of a government public building – the Ras Alain Multipurpose Hall. The analysis demonstrated that 3D printing reduces the total material cost by 65% when compared to conventional construction. The study also demonstrated that 3D printing was faster and more accurate building technology with lower labour costs while minimising waste generation. The cost-benefit analysis of 3D printing was based on construction time, waste production and building embodied energy.

Structural flexibility is also one of the key aspects that add to the competitive edge of 3D printing, as it can create more efficient and interesting designs with unconventional shapes and form at greater precision levels. 3D printing is also lauded for its environmental benefits as it can help reduce the use of raw materials and CO_2 emissions due to lower levels of embodied energy. Although the review evidently notes some added benefits of the use of concrete 3D printing, Allouzi *et al* (2020) notes several areas that still require further research. These include diversity of printable materials, structural design guidelines and architectural modelling processes. Additional recommendations suggested a need for raising awareness,

inclusion of 3D printing in teaching curricula as well as incentives for contractors and engineers to encourage the application of 3D printing.

Hossain *et al* (2020) also covered the impact of 3D printing construction on construction skills and labour. The study focused on how 3D printing could replace conventional construction skills. Studies of this nature are imperative when looking at the potential gains and losses that may be incurred, as the construction industry is one of the most labour-intensive sectors in modern economies and replacement of skills by automation could render a large proportion of the semi-skilled labour force unemployed. Moreover, the construction industry is deemed to be one of the main sources of employment for a low skilled labour force, especially in developing countries like South Africa. Hossain *et al* (2020) however find that 3D printing can reduce a significant number of labour challenges such as the job shortage in the low skilled labour market (particularly in developed countries) and also improve on productivity, occupational health and safety in the sector.

Given that 3D printing is less dependent on human resources and manual processes, it is commonly deemed to be beneficial to developed countries where labour supply is limited and can therefore be problematic for developing countries where a significant proportion of the workforce in the construction industry is semi-skilled. While the inevitable uptake of automated building technologies in construction may result in job cuts in developing countries, it would also create opportunities for other sophisticated and more specialised skills as workers may be increasingly required to work in contexts which entail varying combinations of both digital technologies and manual skills. While the use of automated building technology like 3D printing is anticipated to be increasingly utilized, the use of 3D printing in construction is still in the research and development stage with limited precedents around the world (Hossain *et al*, 2020). The approach therefore falls outside the scope of this study mainly because there are currently no cases in the Johannesburg context, that have been executed on the basis of the technology beyond prototyping stage.

1.10 Structure of the Report

The research report is structured into six chapters as the follows:

- **Chapter 1** sets the foundation for the study and therefore introduces the research by providing the rationale and background for the study. The problem statement is then articulated along with the aim and objectives of the study. The chapter includes the statement of the main research question and related sub-questions followed by definition of key terms, delimitation and this chapter outline

- **Chapter 2** reviews the relevant readings in terms of theoretical and empirical contextualisation of the study. The appraised studies are centred on the concept of decarbonising buildings through responsive selection of building materials and the application of innovative technologies. It also elaborates on the state of the South Africa's construction industry and building materials market as well as related insights on experiences with interlocking blocks in other African cities

- **Chapter 3** presents the method that guided the research process as informed by the research question and sub-questions. The presentation covers the various sources of data, type of data required as well as the tools and methods used to extract and analyse the data in order to derive the required sub-findings as well as overall findings of the study

- **Chapter 4** responds to sub-question 1 and 3 and therefore presents data and analyses on the factors that influence the diffusion of interlocking blocks and other related Alternative Building Materials and Systems (ABMS) as guided by the sub-questions. In particular, the analyses elaborate on the difference between interlocking blocks versus conventional bricks. The chapter also analyses data and information on market-perceptions on interlocking blocks in order to derive sub-findings on market opportunities of interlocking blocks as well as identify key perceptions in the market

- **Chapter 5** presents data and analyses in response to sub-question 3 and 4. It reflects on barriers and concerns that limit the diffusion of interlocking blocks. The chapter also discusses challenges related to the institutional support offered and access to innovators within the area of ABMS. The chapter also highlights the areas that require attention for better diffusion of interlocking blocks and other ABMS

- **Chapter 6** consolidates the sub-findings in order to respond to the main research question. It therefore highlights ways in which the adoption of interlocking blocks and other ABMS can be accelerated in the provision of residential development. It also stresses the need for supporting ABMS by discussing the support that can be given to increase uptake and acceptability of modules like interlocking blocks. The chapter also provides concluding remarks that reflects on the overall discussion as well as the key insights emerging from the study. Finally, the chapter presents recommendations for further studies towards improving uptake based on insights from the study and therefore suggest further exploration of related topics that were not explored in depth in the study

CHAPTER 2: LITERATURE REVIEW ON ALTERNATIVE GREEN BUILDING MATERIALS

2.1 Introduction

Based on the appraisal of relevant studies, this chapter provides a theoretical and empirical contextualisation of the study and thus provides the opportunity for derivation of the conceptual framework as guided by the research question and working hypothesis presented in Chapter 1. The chapter appraises studies on low carbon building materials, the status of GBM, as well as responsive innovations and resultant technologies. On the empirical context, the chapter reviews related regulations and policies that inform the construction sector, the building materials market and construction waste reduction.

The literature review is therefore based on the following key themes of the study:

- Decarbonising the built environment
- Situational analyses of Innovative Building Technology (IBT)
- Policy frameworks, regulations and standards
- Construction and building material trends in South Africa
- Conceptual framework

2.2 Decarbonising the Built Environment and Construction Sector Activities

Increasing urbanisation coupled with the resulting demand for housing should be addressed through sustained investment and innovation, which would entail strategic use of appropriate building technologies that mitigate the degradation of the natural environment (Wazir *et al*, 2014). Given that an estimated 39% of the overall global carbon emissions emanates from buildings, decarbonising the built environment sector needs to be prioritised as a key strategy towards mitigating climate change (World Green Building Council, 2019). Proponents of green energy and technology often define decarbonisation as the process of urgently taking intentional actions and choices that will reduce carbon emission in a specific sector (NBI, 2021).

Decarbonisation prioritises efforts, instruments, controls and processes that will help achieve targets towards net- zero emission by 2050 and create environments that are resilient to the impacts of climate change. The drive for decarbonisation is a global commitment where countries contribute to the climate challenge by relooking at key heavy emitting sectors in order to encourage the use of low-carbon energy without negatively affecting economic development. In the South African context, the built environment and construction are two of the lead sectors in CO_2 emissions (NBI, 2021). This study argues that a paradigm shift towards

decarbonizing the construction sector requires a change from business-as-usual in the area of design and material specifications towards low carbon building materials.

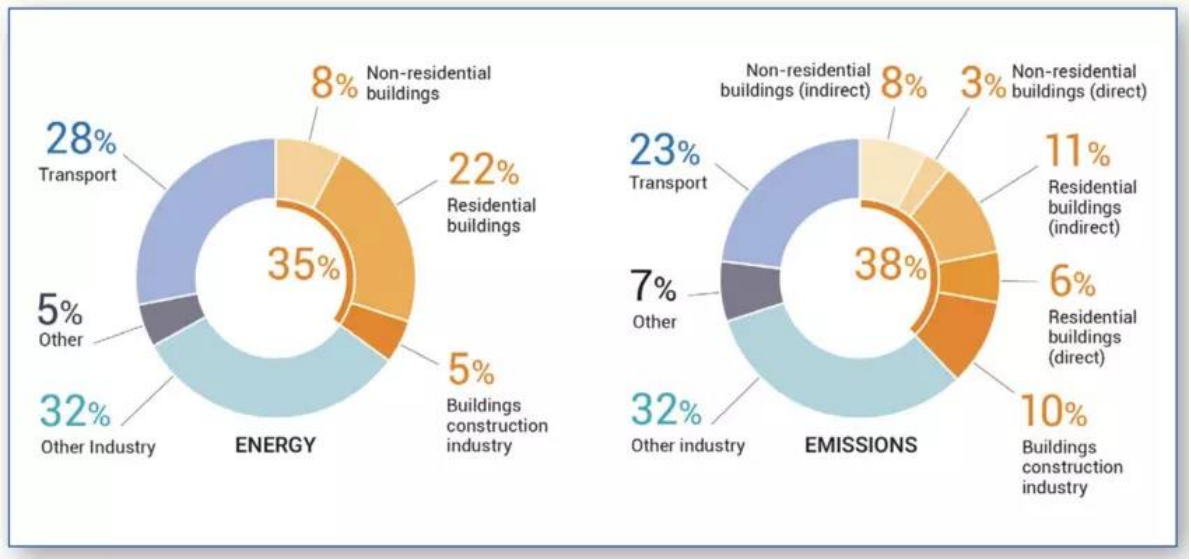

Figure 3: Global share of energy use and emissions of building and construction sectors (Source: Rose, 2022: 5).

Relevant to this study is the use of the block-by-block approach to decarbonise the construction industry, with particular reference to the housing sector. As shown on Figure 3, this sector consumes over a third of the global energy use while contributing to a similar proportion of global emissions (Rose, 2022). In response to this challenge, the reduced whole-life-carbon target could be reached through the following:

- Prudent project planning and execution along the supply chain
- Carefully considered design decisions
- Encouraging use of new and greener construction techniques
- Improved and innovative selection of building materials such as interlocking bricks

With reference to the last point, Dabaieh *et al* (2020: 12) demonstrates how *"choosing the proper building materials can minimize energy consumption, production costs, and [most importantly] environmentally deleterious effects, such as those caused by CO_2 emissions"*. Other studies with similar findings have highlighted the decarbonisation of buildings and construction activities as one of the immediate and most critical issues, which can be tackled from this vantage point.

2.2.1 Defining Embodied Energy (EE)

The agenda for reducing carbon emissions resulting from activities within the construction sector has primarily been focused on operational energy, without much consideration of

embodied energy, even though embodied carbon contributes 11% of all global carbon emissions (World Green Building Council, 2019). However, recent trends reflect a growing interest and awareness of the relationship between embodied energy and GHG emissions as well as the need for the evaluation of other related impacts of building materials and construction activities (Cabeza *et al*, 2021).

In order to ensure common understanding of key concepts and how they are adapted and utilised for this study it is important to appraise studies on how low embodied energy is defined and applied for purposes of this study. Cabeza *et al*, (2021) provides a number of distinct definitions of embodied energy (EE) from different authors within the context of Life Cycle Analysis (LCA). Figure 4 shows the different stages and boundaries of LCA from cradle-to-gate to cradle-to-cradle and how each author defines EE along each segment of the full cycle. This study adopts the definition provided by Abey and Kolathayar (2020), which focuses on the cradle-to-grave segment. Their study defines EE as the total energy consumption linked with a product or system inclusive of extraction, processing, transportation, placement, maintenance and disposal.

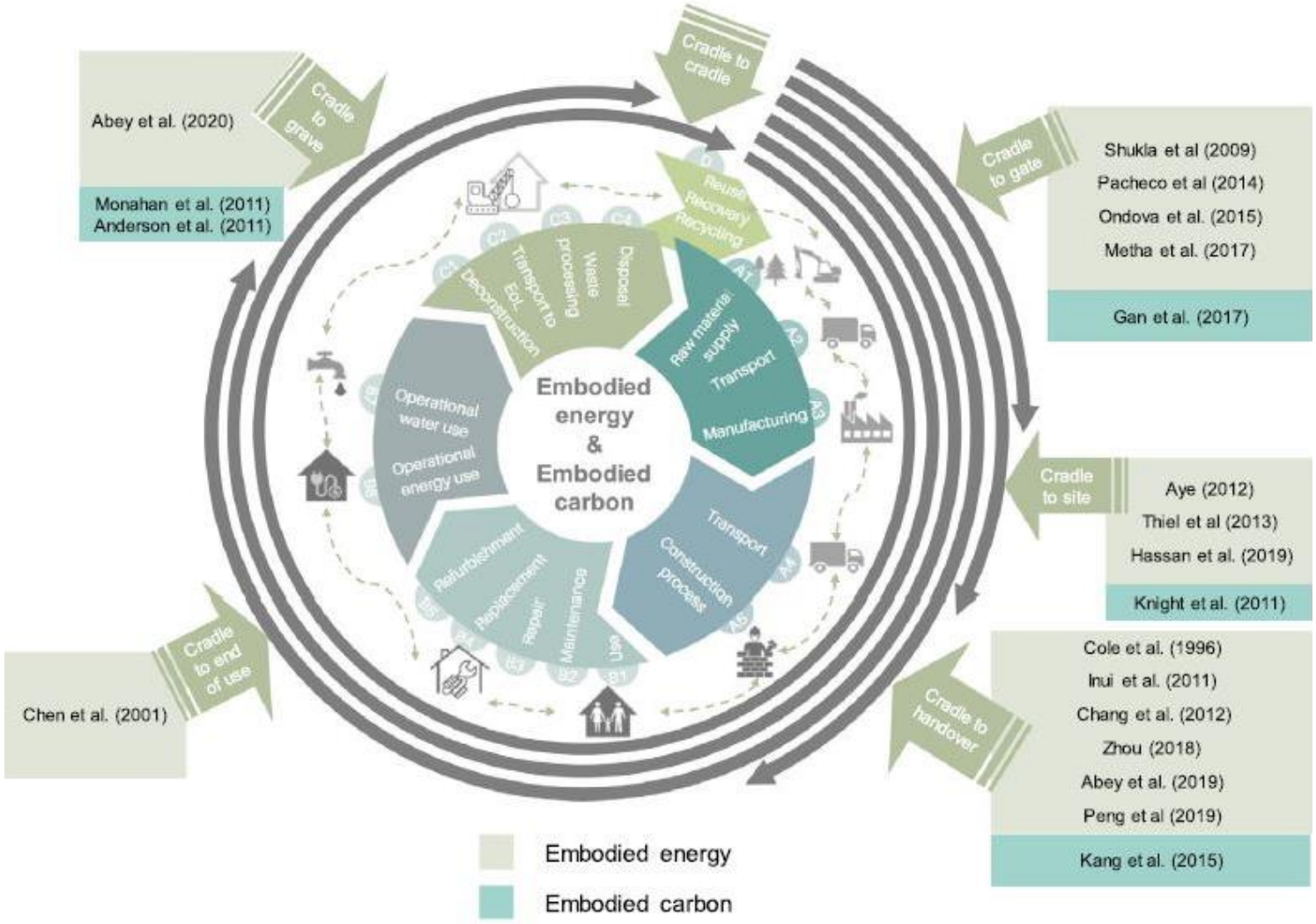

Figure 4: Embodied energy and embodied carbon definitions/concept across life cycles stages (Cabeza et al, 2021:2)

LCA considers the entire life cycle of a building in order to get a comprehensive understanding of the environmental burden due to impacts of related products, processes and activities. However, Cabeza *et al*, (2021) highlights that there is a general agreement that embodied energy is not easily quantifiable or measurable. Zaini *et al*, (2016) states that life cycle analysis (LCA) is one of the most widely used building environmental impact techniques that also considers EE in buildings. This is one of the reasons why EE is measured across LC of the product concerned.

This study is therefore interested in the translation of holistic carbon footprint due to embodied energy used in the entire construction process of interlocking blocks. This includes extraction of raw materials, processing of the materials into components and their assembly, transportation, maintenance and repair as well as demolition and disposal. The key insight from Cabeza *et al*, (2021) is a clear general understanding of how EE has been defined over the years and how this has informed the most recent definition to cover all the processes from cradle-to-grave. Another useful insight is that method for a standardised embodied energy calculation is still an underdeveloped field that requires more research. Although quantifying embodied energy and related carbon-footprint for various products is still a challenging task this does not diminish the business case for decarbonising the construction industry at all project development stages where there is opportunity to do so in order to achieve reduced emissions, increased energy efficiency and improved resilience to climate change.

The London Energy Transformation Initiative (LETI, 2021) in collaboration with Royal Institute of British Architects (RIBA), the Greater London Authority (GLA) and the IStructE have produced a number of documents that introduce a rating system for the embodied carbon footprint across common building typologies such as office, residential, education and retail. Table 1 presents the recommended thresholds of embodied carbon intensity across different buildings types. The table also shows different quantifiable embodied carbon targets and benchmarks such as the notable best-practice performance at C and robust stretch target starting from B going upward. This is part of a bigger programme under the 2030 Climate Challenge whose core mandate is to reduce emissions significantly by the year 2030 and ultimately achieve net zero carbon by 2030 across all building stock in UK (RIBA, 2021).

Table 1: Embodied carbon letter targets for four key building typologies. (Source: LETI, 2021: 3).

Upfront Carbon, A1-5 (exc. sequestration)

Band	Office	Residential	Education	Retail
A++	<100	<100	<100	<100
A+	<225	<200	<200	<200
A (LETI 2030 Design Target)	<350	<300	<300	<300
B	<475	<400	<400	<425
C (LETI 2020 Design Target)	<600	<500	<500	<550
D	<775	<675	<625	<700
E	<950	<850	<750	<850
F	<1100	<1000	<875	<1000
G	<1300	<1200	<1100	<1200

Embodied Carbon, A1-5, B1-5, C1-4 (inc. sequestration)

Band	Office	Residential	Education	Retail
A++	<150	<150	<125	<125
A+	<345	<300	<260	<250
A	<530	<450	<400	<380
B (RIBA 2030 Built Target)	<750	<625	<540	<535
C	<970	<800	<675	<690
D	<1180	<1000	<835	<870
E	<1400	<1200	<1000	<1050
F	<1625	<1400	<1175	<1250
G	<1900	<1600	<1350	<1450

All values in $kgCO_2e/m^2$ (GIA)

Based on World Green Building Council, (2019), Table 1 illustrates the four different stages of project development and the estimated carbon reduction potential at each stage. The table suggests that the greatest reductions would be typically achieved at the planning and design stages of the project. During these stages platitudes such as building less and building clever serve as constant provokers for rethinking the overall approach and process. However, this study goes beyond the early stages by emphasising the potential benefit of exerting efforts across design to the construction stages where there is an opportunity to yield better results.

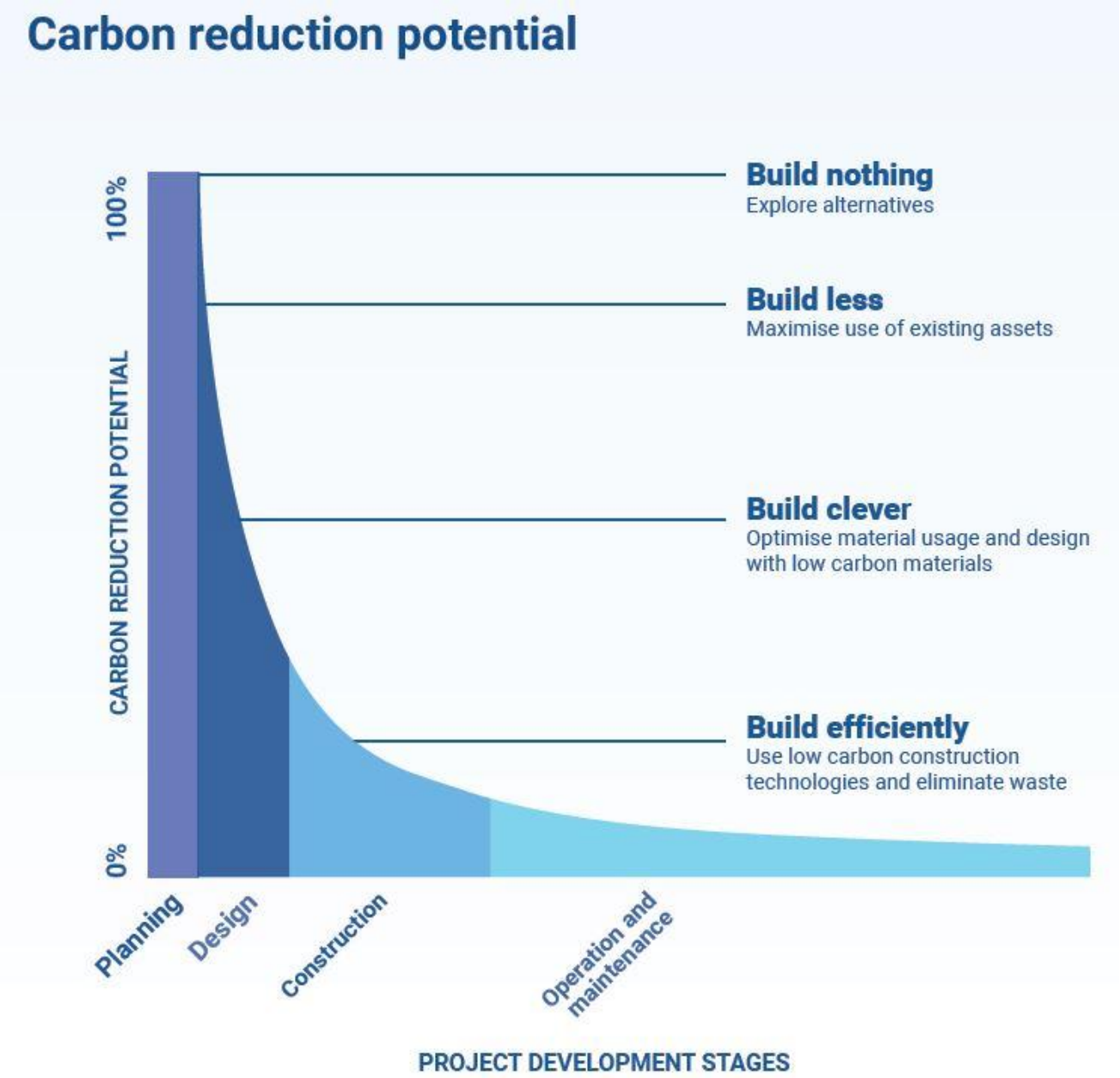

Figure 5: Opportunities to reduce embodied carbon from stage of design process. Source: (World Green Building Council, 2019:20)

Such an approach of intentional focus on embodied carbon, which accounts for all life-cycles stages, is vital in order to optimise overall emissions reduction of a project.

The report also notes that the business case for reducing embodied energy is often inadequately understood thus making resources required to conduct assessments and implement reduction measures difficult to justify. The challenges revolve around low awareness levels and weak demand, inadequate technical skills and capacities, unresponsive policies and regulations, limited technical options in the market and inadequate financial support.

2.2.2 Status of Green Building Materials (GBM) in Construction Industry

Green Building Materials (GBM) denote materials that are environmentally sensitive but still offer high performance on energy efficiency. GBM are typically indigenous, renewable, reclaimable, recyclable and non-toxic in their production processes (Eze *et al*, 2021). They are also critical elements to be considered in pursuit of more green building projects which target reduced emissions associated with embodied energy. GBMs and associated green buildings can therefore be targeted towards addressing socio-economic and environmental concerns in the built environment particularly for cities in developing countries (Oguntona *et al,* 2019).

Eze *et al* (2021) make a compelling argument for the incorporation of GBM by assessing their benefits in Nigeria's construction industry based on responses from construction-based professionals. The study findings indicate that while there is increasing knowledge around green building practises and materials among construction-based experts, the integration of GBM in developing countries is still low (Eze *et al*, 2021). The GBM market remains an underdeveloped and under-tapped market underpinned by an inverse relationship between awareness and adoption rates. The low adoption is primarily attributed to lack of attention given to sustainability agenda and the inertia to shift from undesirable status quo modes. In particular, the study notes that only a few of the respondents demonstrated the adoption of GBM in their projects even though they had a basic understanding of their value.

Oguntona *et al* (2019) investigated the benefits and constraints of implementing green building projects based on South African experience and found that there is a growing interest in green materials. The study then cites an example where tenants are beginning to inquire about green features of a building before occupation. The electricity and water crises mostly felt through frequent outages and water cuts in recent years, have built a sense of awareness around resource consumption, thus giving green products a need-based entry into the market. The study also found that more financing options contributed towards market improvement for green products. Similar adoption benefits were attributed to enhanced educational and technical skills programs on green building materials and greening agenda in general.

2.2.3 Benefits of Incorporating GBM

The benefits of green building products cut across health, socio-economic and financial benefits as well as reducing the negative environmental impacts. Simpeh and Smallwood (2018) examined the benefits of green building in the South African context and established that the highest rewards are reduced energy, water consumption, operational costs, life cycle energy costs as well as enhanced value and profitability of assets. In addition, the emergence of a market for green and sustainable construction creates new opportunities which enhance

demand for green products and services as well as broadening the range of supply for construction materials. The incorporation of GBM also has the potential to facilitate further specialisation among construction professionals and the emergence of new forms of employment and job opportunities.

Eze *et al* (2021) argues that increased demand and acceptance of GBM constitutes a critical step towards the development of green buildings. On the other hand, highlighting the critical benefits of GBM products and related services to uninterested construction stakeholders can increase their appetite and demand of GBM which would in turn incentivise supply. If successful, such a chain-reaction could lead to specialisation and new forms of employment opportunities as well increased diversification of the construction market and company differentiation in the broader built environment sector.

2.3 The Case for Change: International, National and Local Policy Frameworks

With approximately 65% of the national population residing in urban areas, the rapid rate of urbanisation experienced in South Africa demands cities to be pioneers of better governance and sustainable spatial planning (Wolpe and Reddy, 2015). Cities are tasked with promoting resource conscious consumption patterns and reducing GHG emission trends. The pressing need to reduce carbon emissions demands more creative responses and innovative strategies for the construction sector in view of the intensifying development needs and demands.

In an effort to reduce emissions arising from its development initiatives, South Africa has committed to a number of national economic development plans that incorporate climate-resilient growth (Wolpe and Reddy, 2015). This reflects commitment to low carbon development as a national priority. The sample of demonstrative policies and commitments at national and CoJ levels are shown in Table 2. The commitments are set out to foster the transition to low carbon development, urban resilience and low carbon economy and investment in green sectors for net-zero emissions and resilience by 2050.

Tables 2, 3 and 4 below demonstrate that there is consistent consideration and adequate policy frameworks at different levels to guide effective transition towards carbon neutral practice and low carbon development that takes cognisance of the impacts of GHG emission. The policy commitments and aspirations prove that South Africa regards climate change as a critical threat which calls for meaningful change as well as vertical and horizontal coordination between the spheres of government.

2.3.1 International Level Commitments

Table 2: South Africa's international commitments to climate change response: Sources: (DFFE, 2018: 8)

Year	Commitment /Policy	Objective
1997	SA ratified to the United Nations Framework Convention on Climate (UNFCCC)	Commitment to meaningfully engage in the multilateral negotiations to further strengthen and enhance the international response to climate change (DFFE, 2018).
2015	Paris Agreement	SA formed part of the countries that climate pledged to limit the average global temperature and reduce the country's GHG emissions, which was captured at 460 million tons in 2015. Signatories are required to communicate their Nationally Determined Contribution (NDC) to the UNFCCC every five years (CoJ, 2021).
2020	Glasgow COP26	Pressed further on zero-carbon economies by 2050 however, South Africa did not sign the agreement to phase out domestic coal, stating the risk related to coal-related jobs. The major implication for South Africa at COP26 was the pledge to support SA's pathway to low emissions and climate resilient development through financing and grants from the UK, USA, UK, Germany and France (IETA, 2021).

2.3.2 National Commitments

Table 3: National commitments to climate change response. Sources: (DFFE, 2018: 10)

Year	Commitment /Policy	Objective
2004	National Climate Change Response Strategy	To provide support to the principles outlined on the Government White Paper related to energy and emissions.
2007	National Long-Term Mitigation Scenarios defined	Planning process that underpins SA climate mitigation policy.
2011	National Climate Change Response Policy (NCCRP) White Paper published	Provides strategic approach for long term transition to a low carbon and climate resilient society.

2012	National Development Plan 2030	Advocates for the growth of transformed human settlements with stronger efficient spatial planning systems. Chapter 5 maps a vision for the country's priorities in relation to achieving a plateau and decline trajectory for GHG emission and zero emission building standards by 2030.
2015	National UN Sustainable Development Goals adopted (SDGs)	SDGs respond to a range of sustainability development challenges. Most applicable goals to low carbon development and climate change are: Goal 7- Affordable and Clean energy as well as Goal 13 – climate action (DFFE, 2018)
2020	National Climate Adaptation Strategy for 2020 launched	Strategy supports the realisation of the Paris Agreement climate change obligations.
2020	National South Africa's Low Emission Development (LED) Strategy published	The SA LEDS 2050 aims to succinctly build upon the foundation of preceding policies and outline the path going forward in order to encourage the use of low-carbon material.

2.3.3 Johannesburg Local Level Commitments

Table 4: City of Johannesburg's commitments to climate change response: Source (CoJ, 2021:22)

Year	**Commitment /Policy**	**Objective**
2006	CoJ established a dedicated Environment and Infrastructure Services Department (EISD)	Champion department dedicated to environmental issues of the City that is entrusted with shaping relevant municipal policy for sustainable development.
	Joburg becomes C40's member cities	Under C40's Deadline 2020 initiative, Johannesburg has made a public commitment to develop and implement an ambitious Climate Action Plan.
2011	2040 Growth and Development Strategy (GDS)	Provisions for a resilient, livable, sustainable urban environment, compatible with a healthy natural environment underpinned by infrastructure that is supportive of a low-carbon economy. Articulated clear goals for achieving a low-carbon economy and urban resilience.
2015	Climate Change Strategic Framework	Defines adaptation goals and sets specific GHG emission reduction targets.
2021	Climate Action Plan (CAP)	Intends to green municipal infrastructure and create a sustainable urban environment which signals the City's commitment to address climate change as a social justice imperative.

Although the policies reflect a significant level of ambition, Climate Action Tracker (CAT) deems South Africa's efforts as insufficient and therefore highlights additional government and political initiatives to take climate change to a higher priority (CAT, 2020). The low economic growth due to energy sector challenges is anticipated to further hamper further gains in this aspiration. The country therefore needs to prioritise investment towards a 'green' recovery at the backdrop of the devastating impacts of COVID-19 pandemic.

2.3.4 Legislation that Informs the Design and Construction of Homes

The design and construction of homes in South Africa is governed by a set of policies and legislation which are important to consider as they influence the choice and use of all building materials. The policy frameworks would also influence the uptake and acceptability of interlocking blocks and other similar low carbon building materials. The pieces of legislature that inform the design and construction of homes are identified and are briefly discussed along the timeline of their coming into effect as shown in Figure 6.

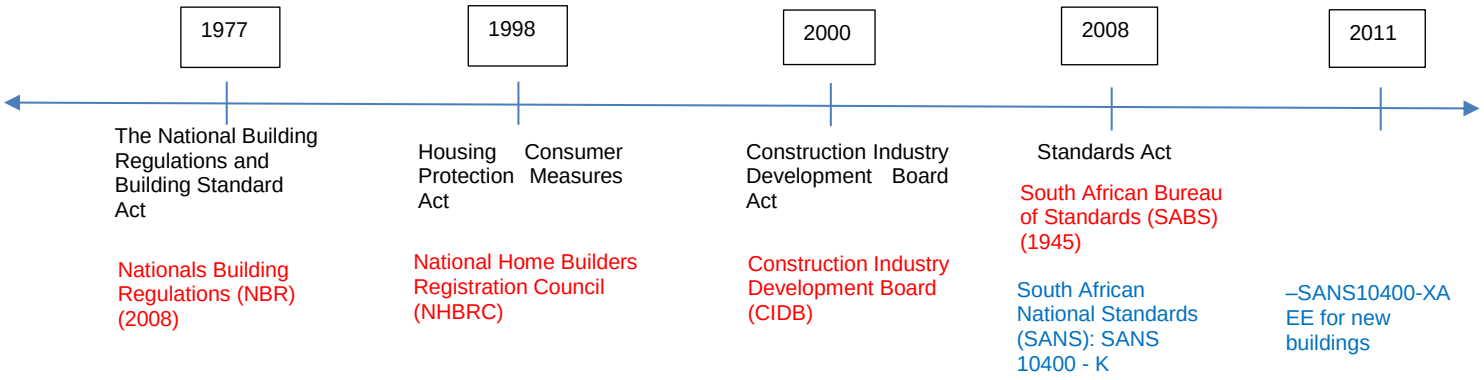

Figure 6: Timeline of policies that influence design and construction of homes

Table 5: Brief description of the objective and outcomes of the legislation.

Act	Objective and Outcomes
The National Building Regulations and Building Standard Act	The act regulates the manner in which homes are built to ensure the well-being and safety of the owners/users. It also strengthens the powers of the National Regulator for Compulsory Specification. In 2011, the South African National Standard (SANS) 10400 – XA 'Energy Usage in Buildings' regulations were added to the National Building Regulations for Energy Usage in Buildings to improve energy efficiency of new buildings. The amendment also aims at ensuring that new buildings comply with maximum energy demand and maximum annual energy consumption under respective climate zones. This promotes the consideration of energy efficiency in the design and construction of homes as well. **Outcome:** promulgated from this act is the National Building Regulations (NBR) (2008). Building codes and regulation ensure that structures can support specific weights and pressures and have the required strength to meet the conditions for a liveable structure. The NHBRC incorporates the consideration and promotion of the piloting as well as the use of Innovative Building Technology (IBTs) in response to housing crisis and negative environmental contribution of the construction sector.
Housing Consumer Protection Measures Act	This act is concerned with ensuring that consumers get a warranty protection in new homes against major structural defects and roofing leaks **Outcome**: The National Home Builders Registration Council (NHBRC) was formed through this act to be the statutory body that protects the interests of all those involved in the delivery of residential units. The function of the NHBRC is also to regulate the home building industry through specified ethical standards and technical standards.
Construction Industry Development Board Act	**Outcome**: Construction Industry Development Board (CIDB) which allows for the implementation of an integrated strategy for the reconstruction, growth and development of the construction industry.
Standards Act	The Standards Act of 2008 was set out for the development, promotion and maintenance of quality standardisation of commodities and services. Through this act, the South African Bureau of Standards (SABS) was established and tasked to be the statutory body to develop and oversee the South African National Standards (SANS). Standardisation is seen to be important for the path from research product development to the local and international marketplace to ensure consistency and quality assurance. **Outcome**: The South African Bureau of Standards (SABS) introduced the SANS 10400: the application of the National Building Regulations issued in terms of the National Building Regulations and Building Standards Act, 1977 (Act No. 103 of 1977). For the purpose of this study, the most relevant section is the SANS 10400-part K, which sets out the deemed-to-satisfy for good practice in masonry wall design and construction. Part K provides key guidelines for the building of masonry walls using interlocking blocks as well.

In order to advance climate change action and support low emission development, Wolpe and Reddy (2015) state that the country needs improved institutional multi-level governance and finance mechanisms to guide scale up of bold local action. Efforts to uphold these commitments call for all spheres of government to play an active role through institutional and market driven support, especially at local level where most of the change needs to occur. Specifically, the commitment to low carbon emission strategies aligns with the use of low carbon IBTs, and cities are the main arenas of change where innovative strategies can be implemented to create more resilient urban built environments. In the same vein, building institutional and financial support requires raising awareness of the co-benefits of low carbon development, mainstreaming climate change action into municipal development finance system and building control standards as well as identifying and implementing innovative finance agreements to unlock access barriers to capital markets (Wolpe and Reddy, 2015).

2.4 Construction and Building Material Sector in South Africa

The South African construction industry is responsible for the planning, design, construction, maintenance and demolition of buildings and infrastructure. As a result, it plays a significant role in the growth of the economy and related employment opportunities, particularly for the non-skilled and semi-skilled working population. It is estimated that the industry contributes at least 50% to the country's national capital investment while accounting for approximately 4% of the Gross Domestic Product (GDP) (Pillay and Mafini, 2017).

Private and public sector infrastructure developments are, to an extent, the key drivers of growth and development of South Africa's construction industry. For instance, the government's human settlement programme aimed to construct 1.5 million homes by 2019 and with regards to education, the government aimed to replace 510 education buildings by 2023 (Pillay and Mafini, 2017). Given the slow progress towards these targets, the backlog may have increased considerably in the last couple of years. Other contributing factors to the backlog include the destruction of property such as schools and malls during the 2021 social unrest as well as the constantly increasing rates of urban migration. The impact and contribution of the construction industry to economic development and employment places pressure on the industry to grow at faster rates and remain productive. This also presents an opportunity to explore innovative low carbon construction technologies such as interlocking blocks and other sustainable building materials.

2.4.1 Trends in Building Material Prices in South Africa

With material cost being one of the big-budget components in new construction projects, access to affordable building materials is therefore an important factor to consider. Building material costs are argued to range between 35 - 60% of total construction costs of a project depending on scale and type of development (Windapo and Cattell, 2012: 188). The study also noted that while gradual price increases are generally anticipated on all goods and services, steel, cement, copper, timber, PVC and masonry blocks/ bricks tend to be volatile materials in terms of price changes in the South African market. Table 6 shows the highly cost-volatile building materials in the country. Through a study of the patterns of building material costs the study also identified a range of factors influencing prices of building materials. The factors include supply/demand, inflation, exchange rates, transport costs and production costs. Price increases in these materials is a cause for concern with regard to competitiveness of green building materials in contrast to existing conventional products.

Table 6: Highly volatile building material. Source: (Windapo and Cattell, 2012:197)

Building Material	**Scale**			**Total Response**	**MIS Score**	**Rank**
	Highly Volatile (3)	**Volatile (2)**	**Not Volatile (1)**			
Steel	36	14	1	51	0.90	1
Copper	23	21	4	48	0.80	2
Cement	21	21	9	51	0.75	3
Bitumen	14	28	8	50	0.71	4
Lumber	7	24	17	48	0.60	5
Masonry bricks/ blocks	6	22	21	49	0.56	6
Sand	3	25	22	50	0.54	7

2.4.2 Construction Waste Reduction

The activities of the construction industry have both positive and negative consequences on the environment. One of the most notable negative impacts is construction waste across the various stages of the materials process. With increasing urbanisation and related construction activities, Johannesburg and other African cities generate large amounts of solid, liquid and gaseous construction waste. Aboginije *et al* (2020: 2430) claim that construction and demolition debris typically constitute 10-30% of the waste collected at landfill sites around the world and then emphasise that approximately 15% of all materials delivered to a construction site ends up in landfills as construction waste due to inadequate waste mitigation strategies in the construction process.

In line with the scope of EE as defined in Abey and Kolathayar (2020: 169), it is also important to consider the effects of disposal after construction. In the South African market, the

construction industry is estimated to generate 5-8 million tons of construction and demolition waste per annum. Oyenuga and Bhamidimarri (2015) note the leading development type when it comes to generation of excessive waste is the development of large scale high-density residential buildings as well as large scale housing projects on single stands. Furthermore, only a small fraction of the waste generated from these projects gets recycled into secondary materials. It is also argued that a significant portion of the total waste is indiscriminately disposed in illegal dumps mainly in public open spaces. The reduction of excessive post construction waste requires more urgent attention and intervention if the country is to work towards the set emission and energy efficiency targets. Business-as-usual should no longer continue to be a viable option for those involved in the industry.

2.5 Conceptual Framework

This research report argues that in order to increase the uptake of interlocking blocks and thus leverage the low-carbon outcomes of the technology, a two-pronged approach needs to be employed. As shown on the conceptual diagram in Figure 7, this would entail the support of market-oriented initiatives aimed at 'Benefit Promotion' and 'Barrier Removal'. With reference to the promotion, initiatives should aim to increase awareness of the benefits associated with the use of green building materials. Such initiatives ought to promote stronger synergies among key role players in the industry in order to also reduce the barriers that limit overall uptake of innovative low carbon construction strategies which would facilitate the realisation of carbon conscious developments. The conceptual framework provides further elaboration on the basic concepts and themes that guided data collection, presentation and analyses as well as derivation of findings of the study.

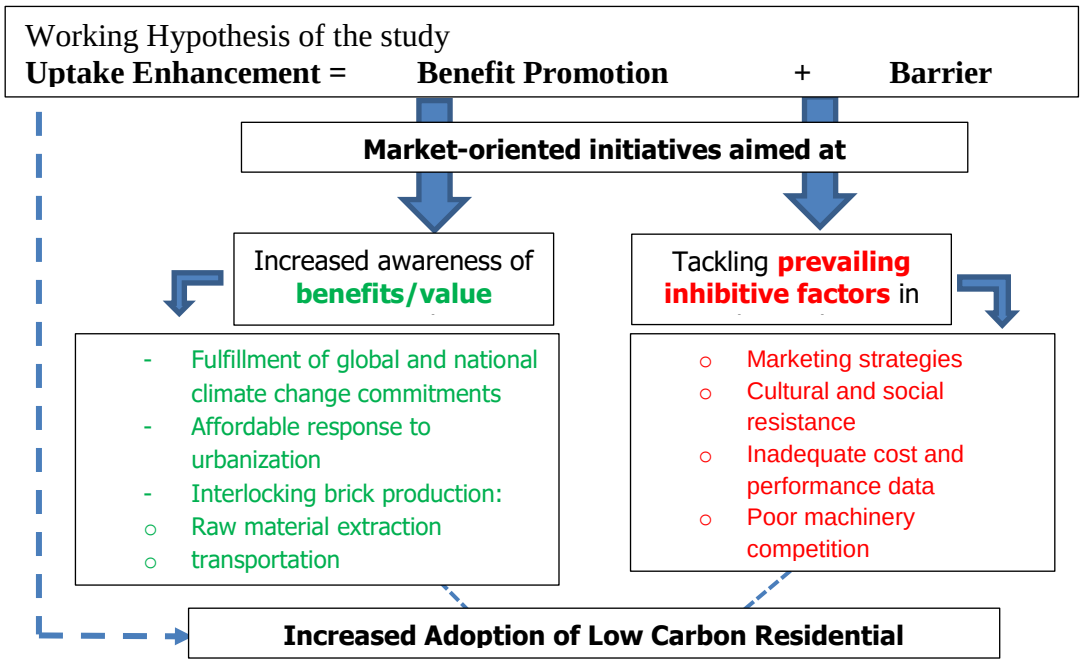

Figure 7: Conceptual framework reflecting the research working hypothesis.

2.6 Conclusion

The key insight from literature review is that the promotion of low carbon and low emission development is of national and global importance, particularly for cities in developing countries importance of decarbonising the construction industry as the proportionate project costs set aside for building materials would guarantee a considerable reduction of GHG emissions if carefully leveraged. This is also due to the fact that an estimated 39% of the overall global carbon emissions emanates from buildings. Small actions with big impact, as suggested in the research, entail prudent project planning and execution along the supply chain, carefully considered design decisions, encouraging use of new and greener construction techniques, improved and innovative selection of building materials such as interlocking bricks.

The study argues that it is important to study the entire life cycle of a building in order to get a comprehensive understanding of the environmental burden due to impacts of related products, processes and activities. But it also acknowledges that methods for a standardised embodied energy calculation are still an underdeveloped field that requires more research. An interesting insight is that the move towards low carbon systems and materials will come at a cost which includes the potential replacement of the labour force because some of the blocks require less human resources to manufacture. Lengthy quality control processes is also identified as one of the constraints to be considered.

The review also identified key pieces of policies, legislation and regulatory frameworks that guide the design and construction of homes and could therefore assist in ensuring delivery of green residential infrastructure at satisfactory standards and quality. This would in turn assist in allaying market scepticism about the use of unconventional, yet sustainable materials and methods of construction in the country.

CHAPTER 3: RESEARCH METHOD

3.1 Introduction

This chapter presents the research method employed to systematically respond to the overall research question. Basias and Pollalis (2018) state that adopting the most suitable research methodology is a key prerequisite to undertaking a successful investigation which ultimately achieves the research objectives. Through the chosen method the study successfully identified areas of improvement and strategies through which the diffusion and use of interlocking blocks and other ABMS can be accelerated for the provision of low carbon human settlements in the Johannesburg context. The chapter outlines how the research proceeded by collecting secondary data from policy documents and literature as well as primary data from interview responses, then analysed the consolidated data in order to derive findings on the main research question.

The chapter further maps out the research design process as well as the rationale and motivation for the specific steps taken to fulfil the objectives of the research. The purposeful sampling approach was employed to obtain descriptive data outcomes from the selected respondents. This is a widely used technique in qualitative research, which allows for an effective use of research resources. Briefly, it allows for the selection of groups or individuals that are well versed in a particular phenomenon of research (Palinkas *et al*, 2015). The chapter is structured into five main parts namely the qualitative research approach, research design and overall approach and ethical considerations.

3.2 Qualitative Research Approach

In view of the nuances on issues related to adoption of ABMS and interlocking blocks, the study opted for a qualitative research approach. Basias and Pollalis (2018) define qualitative research as an overarching reference to research methodologies that embrace the analysis of experiences and behaviours without resorting to statistics and numerical data. Essentially, qualitative research refers to investigative research which prioritises the use of non-numerical data as well as depth in analyses. It therefore demands more in-depth involvement of the researcher in contrast to the supposedly neutral or objectivist approach of quantitative studies (Basias and Pollalis, 2018).

The approach allowed the researcher to study and analyse the selected themes in detail in order to derive insights and findings on how the use of interlocking blocks and other ABMS could be accelerated based on technical, socio-economic, -cultural and policy insights from the sampled respondents. The insights gained thus aided the study towards a deeper

understanding with regard to the policy context as well as market opportunities and constraints related to the current uptake of interlocking blocks. One of the advantages of a qualitative approach is that it allows the researcher to understand the nature and complexities of the field and topic of investigation, especially when it entails the engagement of multi-disciplinary knowledge (Basias and Pollalis, 2018). The approach also allowed respondents to provide more nuanced insights when responding to questions on barriers and opportunities for the diffusion of interlocking blocks. The study therefore focussed on experiences and perceptions of the purposely selected experts from the built environment on the adoption of ABMS and especially interlocking blocks for residential developments within the City of Johannesburg.

3.3 Research Design and Overall Approach

The research process flow of the study is shown in Figure 8 below.

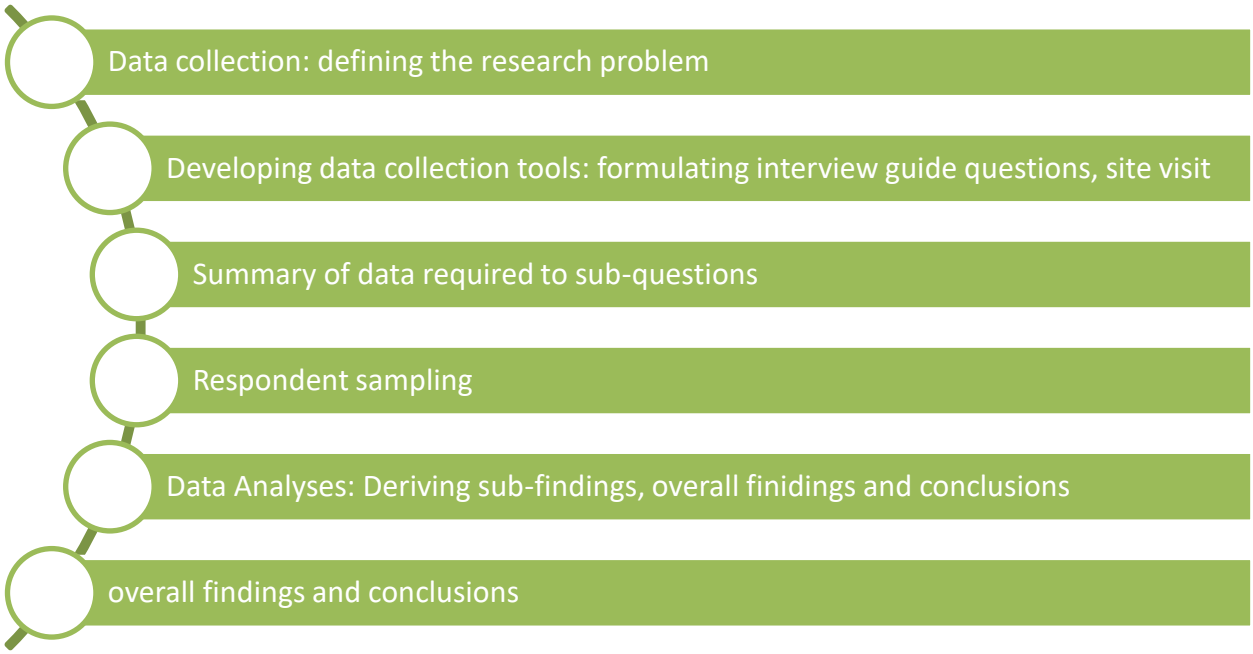

Figure 8: The research process followed in conducting the study

3.3.1 Data Collection

Qualitative data collection tools were employed to gather both primary and secondary data. A significant portion of the secondary data came from the architectural and planning, sustainability as well as material science and engineering journals. Data extraction tools and process entailed the review of selected documents, interview of respondents, direct observation and visual recording (mainly through photography).

At the beginning of the research process, secondary data assisted in identifying the key challenges and developing the problem statement as well as setting the objectives and research goals. Secondary data also highlighted the discussions around decarbonising the built environment, status of green building materials as well as the advantages of incorporating GBMs. The data were also used to review policy related challenges and commitments made towards supporting low carbon development in the Johannesburg context.

Primary data were gathered through field work activities such as site observations of the production process of interlocking blocks and interviews with purposely selected respondents in three key categories of businesses, regulatory institutions and professionals. The interviews were based on semi-structured questions which were adapted to each respondent category. Primary data required focus on the experiences of utilising interlocking blocks, particularly in residential development within the construction materials sub-sector. Primary data collected also focused on the respondents' knowledge base and understanding of the sub-topics as well as the extent of their consideration and willingness to utilise low carbon building materials within their respective roles.

3.3.2 Developing Data Collection Tools

Informed by insights from Chapter 2 (literature review), the study developed a working hypothesis (see Section1.8) to be substantiated through the research process. The delimitation of the scope captured in Section 1.9 also assisted in guiding the boundaries of the areas of interest to ensure that data collection tools closely aligned to the key issues of the research question. Primary data collection tools included semi structured interview questions and one site visit which facilitated direct observation captured primarily through photography. As captured on Table 7 below, the researcher outlined the summary of data required per sub-question then formulated the exact interview questions that would help in soliciting the required information from the respondents. Before the interviews the researcher trialled the interview questions on other personnel to ensure that the questions were adequately framed to guide the anticipated interview process. In terms of organising the site visit, the researcher made a request to join the Hustlenomics team on their workday in which the team would actually make the interlocking blocks for their next project to which the Director agreed and organised the site visit.

3.3.3 Summary of Data Requirements per Sub-Question

This sub-section illustrates the various data sets required for each sub-question, tools used to obtain the data and the data analyses undertaken to address each sub-question. It outlines the different data processes required to derive sub-findings which were in turn consolidated to address the overall research question.

Table 7: Summary of data requirements per sub-question

MAIN RESEARCH QUESTION: How could the diffusion of interlocking masonry blocks be accelerated towards facilitating the provision of low-carbon sustainable human settlements in Johannesburg?			
Research sub-questions	Data needed	Data Source/Data collection method	Data analysis and derivation of sub-finding
Sub-question 1: What are the critical perceptions on interlocking blocks in the Johannesburg housing construction market?	○ Views, attitudes and consideration of interlocking blocks and ABMS ○ Building materials selection process and rationale for choice ○ Awareness of different building materials and their impact ○ Exposure to and level of care for low carbon development ○ Consideration for low carbon development and sustainability	**Primary data:** Interviews with different respondents and experts in the field. **Secondary data**: tender documents, policies, reports	○ The responses to the interview questions were captured in a data overview summary tables ○ Data is displayed in figures and tables to illustrate the outcomes and correlations among the input of the various respondents. Direct policy and tender extracts are included as part of the evidence ○ The outcomes were thereafter discussed, evaluated and compared to the reflections in the literature review and secondary data sources to identify gaps, common ideas, contrary views and the critical perceptions on interlocking blocks and ABMS
Sub-question 2: How do interlocking blocks contribute to the agenda for reducing low embodied energy in housing construction compared to conventional bricks?	○ Difference between conventional masonry bricks with mortar and interlocking blocks (primary focus/emphasis on the environmental costs and benefits)	**Secondary data**: Government policies, academic journals through desktop research	○ Data overview table reflecting the interview responses per respondent ○ Reflection on the differentiating factors, the interlocking blocks production process are presented in a table format with images and descriptions of the various steps and related considerations ○ The experience and benefits of using interlocking blocks are grouped into themes: production,

			financial, performance indicators, environmental factors and supply ○ The outcomes were thereafter discussed, evaluated and compared to the reflections in the literature review and secondary data sources
Sub-question 3: What are the key barriers to the diffusion of interlocking blocks in the residential development sub-sector of the construction industry?	○ Machinery cost of interlocking blocks ○ Availability and accessibility of ABMS in mainstream market ○ Skills required for the use of interlocking blocks ○ Status Quo impact ○ Policy premise ○ Certification processes by regulators	**Both primary and secondary data:** Marketing brochures and expert interviews with different respondents	○ Data overview table reflecting the interview responses per respondent ○ Barriers relayed in sub-topics and further analysed through discussion
Sub-question 4: How can the perceptions and barriers be addressed in order to enhance the uptake of innovative sustainable building materials?	○ Existing incentives for the use of ABMS and IBTs ○ Programmes encouraging the use of ABMS ○ Recognition awards ○ Funding instruments ○ Training programmes	**Both primary and secondary data:** Marketing brochures and expert interviews with different respondents	○ Data overview table reflecting the interview responses per respondent ○ Existing support and areas of improvement discussed through text in sub-topics that were informed by the primary data responses ○ Suggestions for areas of improvement are discussed to derive a potential response to the challenges and enhance the uptake of ABMS

3.3.4 Respondent Sampling

A purposive sampling method was utilised to identify relevant expert respondents. Potential respondents who met the research criteria were subsequently approached and those that were willing to participate were interviewed. Etikan *et al* (2016) define the purposive sampling technique as the intentional selection of a participant due to the qualities and experience the respondent possesses. With the use of this technique, the researcher tailors what needs to be unpacked and sets out to find respondents who meet the criteria of the intended sample group and are willing to provide the required information by virtue of their respective knowledge, informed perception and experience (Etikan *et al*, 2016).

The sampled respondents were interviewed with the use of interview guide questions (see Appendix 3) that were designed to address the sub-questions and main research question in order to meet the objectives of the study. The interviews were conducted via Microsoft Teams and the sampled respondent categories included businesses, organisations and professionals. The engagements successfully yielded the primary qualitative data set of the study.

3.3.5 Profile of Research Participants

This section introduces the sampled respondents that were interviewed to inform the research report. Table 8 below outlines the different respondents' organisation and their respective roles within the organisation. The table also reflects the sampled respondents' years of experience in the field.

Table 8: Research respondent profiles

Group	Organisations Profile	Respondent	Position	Experience
Business				
Hustlenomics	Hustlenomics is a Soweto based for profit social enterprise that is in the business of redeveloping existing backyard housing into more liveable structures using alternative building technologies. Hustlenomics' target market is low-income homeowners with existing informal backyard shacks or makeshift dwelling units and would be interested in formalising and make the structures more liveable but cannot access traditional home improvement financing. Hustlenomics replaces these shacks with durable structures using interlocking blocks.	Respondent A	Managing Director	7 years

Hydraform	Hydraform is a South African owned company that designs, develops and markets patented machinery for making interlocking blocks. The company has been in existence for over 30 years and has contributed to the successful completion of a lot of schools and affordable housing projects across South Africa, Philippines, Rwanda, India, Sierra Leone, Uganda, Tanzania and Kenya using interlocking blocks.	Respondent B	Internal sales	4 years
Organisation				
Joburg Property Company (JPC)	The Joburg Property Company (JPC) is mandated to manage and develop City-owned property assets and land to ensure the optimisation of social and commercial opportunities on behalf of the Council. JPC uses council-owned land assets to leverage private sector investment in public infrastructure for greater development growth and socio-economic value through long term lease arrangements.	Respondent C	Project Manager	3 years
NHBRC	In terms of the Housing Consumers Protection Measures Act, the National Home Builders Registration Council (NHBRC) is tasked to establish and promote ethical and technical Standards in the home building industry. The NHBRC also acts as a regulator for new tools and building strategies in the construction market and thus fostering innovation through its Innovative Building Technology (IBT) research department.	Respondent D	quality assessor within the Research department – specializing in Innovative Building Technology (IBT)	18 years
Professionals				
Nkomaba Trading & Projects	Site manager with a B.Tech in Construction Management. Oversees day to day activities of projects. Work entails the running of multiple projects, overseeing activities carried out within the projects, as well as the coordination of production activities on site.	Respondent E	Site manager	3 years
Independent consultant	Independent Professional	Respondent F	Registered professional Architect, registered lightweight contractor/ erector	5 years

3.3.6 Data Analysis

The primary objective of data analyses was to contribute towards derivation of sub-findings on each sub-question and subsequently to overall findings through consolidation of the sub-findings. The data were analysed in a thematic format using data summary tables to establish both vertical and horizontal connections. As indicated in both Chapters 4 and 5 the data were initially presented in the form of tables (schedules and matrices), images and figures in order to create an overview of primary and secondary data gathered. The qualitative analyses process also involved cross referencing additional secondary sources with the insight from primary data to substantiate some of the views and opinions shared by the respondents. Basias and Pollalis (2018) assert that qualitative research approaches are more natural as the researcher is challenged by the need for interpreting the outcomes in order to draw the final conclusions based on observations and outcomes of the data processes.

3.4 Case Study Presentation: Interlocking Blocks

The key distinguishing factor between interlocking blocks versus conventional bricks is in their mortar-less assembly which is facilitated by their unique geometrical profile. The blocks are manufactured in complex shapes and shades depending on the machinery and the soil utilised. Block colour can also be modified by adding cement dyes but this would translate to cost-increase due to the additional cost of such dyes. Interlocking blocks are further explored in the sub-sections below in terms of equipment and the production process used, in the following sequence:

- The Hydraform Building System: Machinery
- Interlocking Block Manufacturing Process
- Challenges in Hydraform Building Systems

3.4.1 The Hydraform Building System: Machinery

The most prominent interlocking block utilised in the southern African region is the Hydraform block which is produced with the Hydraform machine. The Hydraform innovation comprises of three key parts which are the Hydraform block, Hydraform machine and the advantage of interlocked stacking offered by the Hydraform blocks (Wazir *et al*, 2014). Hydraform blocks are manufactured by hydraulically compressing a soil-cement mixture in a block-making machine as illustrated on Figure 9. The blocks produced through this system go through extensive strength and durability tests (Wazir *et al*, 2014). The mobility feature of the machinery allows builders to produce the building blocks on construction sites, which in turn results in the reduction of embodied energy and cost of transportation of materials. Machinery for making interlocking blocks

are typically offered across a range of varied features such as speed and capacity to suite different project scales.

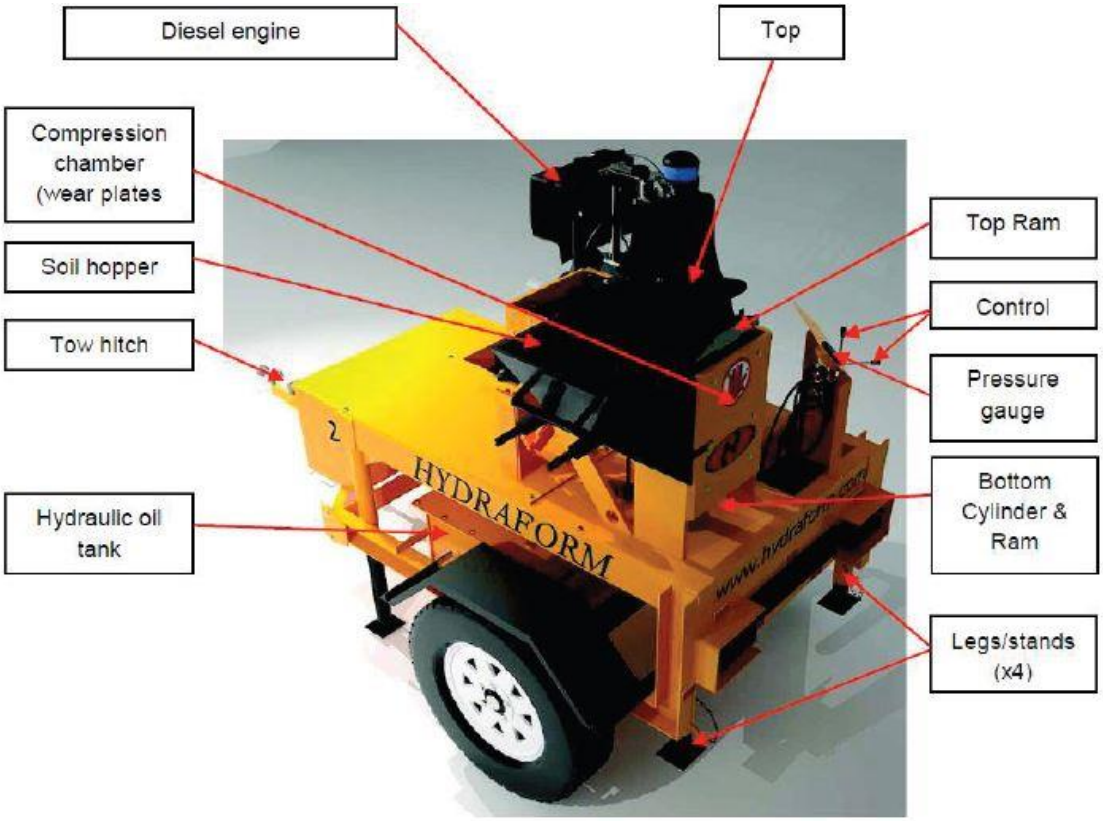

Figure 9: Typical features of a Hydraform interlocking block making machine. Source: (Wazir et al, 2014: 95)

3.4.2 Interlocking Block Manufacturing Process

Interlocking blocks are manufactured through high-pressure moulding with machinery such as the one shown in Figure 9. Gravel, cement and sand are the key raw materials used as inputs (Zhang and Biswas, 2021). The Hydraform interlocking soil-cement technology enables the use of local materials like laterite soils which are stabilized with about 10% cement and hydraulic compaction to produce a compressed earth brick with a thickness of 180mm. The preferred soil type is classified as a sandy – loam soil which can be obtained at sub-soil depths of 0.5 - 1 meter below ground level. This ensures that it is free from organic material and should not contain harmful quantities of salt. The mixture should contain sufficient clay to bind the blocks so that they may be handled immediately after manufacture without disintegrating. Cement is the required stabiliser which is then mixed with the subsoil and about 5 - 10% water (by volume) to produce a slightly moist mix (Zhang and Biswas, 2021). The machines vary in production capacity and mobility and could be powered by diesel or electricity. They also allow for an

interchange of moulds for different block-sizes required for internal walls or capping for boundary walling (Zhang and Biswas, 2021).

3.4.3 Challenges in Hydraform Building Systems

Some African cities are witnessing an increasing use of Hydraform building technology in the housing market. Wazir *et al* (2014) investigated the experiences of using Hydraform building systems for low-cost housing in northern Nigerian. The study found a range of constraints such as delays in the production process as well as unique additional quality control processes. Another challenge noted was the lack of skilled machine operators and trained dry stacking brick layers as well as the slower rates of construction and high cost charged on laying the blocks. While the specific challenges identified from the study may be site specific, they still present a dimension that needs to be considered in the evaluation of interlocking blocks within specific projects. Similar to the challenges noted in Nigeria, this study aimed at understanding and addressing related constraints inhibiting the adoption of the technology in the South African housing development market.

3.5 Ethical Considerations

For ethical considerations, the research was guided by the research ethics policy and guidelines of the University of the Witwatersrand. The researcher obtained formal ethics clearance prior to the commencement of the field work. It is important to note that the study and its investigation methods were deemed to be of low risk in that they did not entail any envisaged physical, psychological or social harm to participants or their respective organisations. As part of acquiring ethical clearance, the researcher also requested and acquired direct permission to mention and observe Hustlenomics' interlocking blocks production process on site.

Respondents were identified and selected by the researcher based on their experience and involvement in the production and use of interlocking blocks and their respective influence in the value chain of residential developments. Some of the respondents were selected according to their general involvement in the construction industry and the broader built environment. All the respondents were informed of their rights to withdraw from the research at any part of the process and that they would not receive any sort of compensation for their participation.

Personal information of respondents such as their profile and basic organisation information was gathered and will be protected as per the Protection of Personal Information Act 4 of 2013 and

Protection of Personal Information (POPI) Act. As part of ethics requirements, participant information sheet was discussed with each participant after which they signed consent forms as declaration of their voluntary participation in the study. At the beginning of each interview session, the envisaged unique contribution of each participant was explained and the researcher committed to ensure anonymity of each respondent both in the process of the study as well as when writing the report. However, with consent by respective participants, names of Hustlenomics and Hydraform are mentioned without anonymisation and as a result, anonymity of respondents could be compromised on basis of online content in the websites of the respective organisations.

CHAPTER 4: FACTORS INFLUENCING THE DIFFUSION OF INTERLOCKING BLOCKS AND OTHER RELATED ABMS

4.1 Introduction

In response to sub-questions 1 and 2, this chapter presents data and analyses on perceptions of the construction market with regard to Alternative Building Materials and Systems (ABMS) as a whole and interlocking blocks specifically. The chapter also reflects on the difference between interlocking blocks and conventional bricks to demonstrate how interlocking blocks contribute to the agenda for reducing low embodied energy in building materials. Due to the nature of this research, data are presented in the form of text and visual demonstrations. Figure 10 shows the structure and approach of the chapter and how it aims to connect to subsequent chapters.

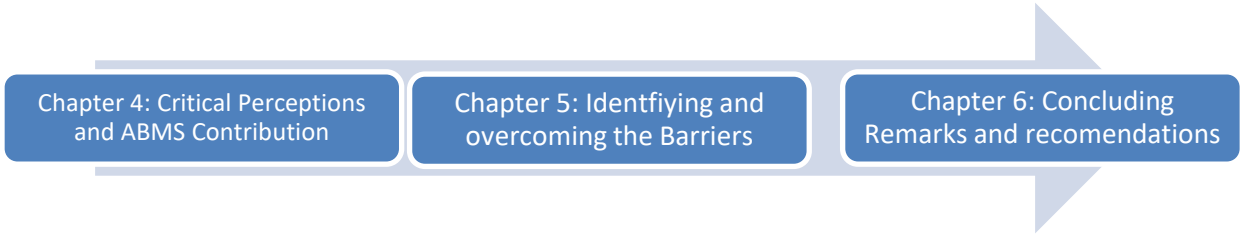

Figure 10: Structure and approach of the chapter.

4.2 Data Overview for Sub-Question 1: Perceptions of Interlocking Blocks

This section addresses the first sub-question which focuses on identifying and discussing the critical perceptions on interlocking blocks that influence building material choices in the Johannesburg housing construction market.

Table 9: Data overview for sub-question 1: Perceptions of interlocking blocks contributing to building material choices in building construction

	What factors influence the choice of building materials for your projects/ organisation/ store?	How would you grade your level of awareness of green building materials?	What are your thoughts on green building materials?	How would you grade your level of the adoption of innovative building materials?	Have you ever considered innovative building technology or materials for your projects/ organisation/ store? If yes, which ones?	Have you ever heard of interlocking blocks? If yes, where did you first hear of it?	If so, what were your initial assumptions of it?
Respondent A	Interlocking blocks are the company's sole selling point. The rationale for this choice was predominately based on it being a much more cost sensitive option than the conventional bricks. It also created some differentiating factor on top of the financing model we offer our clients.	Expert – I work with interlocking blocks specifically	I think they are the future. The world Is pulling towards better building strategies. I have been fortunate to have some exposure to other countries through competitions and have seen how progressive other countries are with being more environmentally friendly in construction.	High – since I am raising awareness and acceptability of interlocking blocks	Yes – interlocking blocks	Yes, Online	I thought it was a cool concept
Respondent B	We are a business-to-business type of company. We supply machinery for businesses looking to build with interlocking blocks. However, even though we do not typically interact with ordinary home makers, we have found that our customers are typically concerned with: costs, quality of bricks, production time, labour costs and exclusivity of the machine.	Expert - I'm in internal sales so I am very informed with interlocking blocks	Innovative building products and technology are going to do very well as people become more informed about such topics and better practice becomes the only logical option. We are struggling right now with market housing, hence the interest now in affordable housing. There are other people, such as those that are on City tender panels that can construct a house in a day using green building materials.	High – But the general adoption of green building materials is still low in SA	Yes - we are in the business of promoting interlocking blocks	Yes, We manufacture and supply the machinery for making interlocking blocks	N/A

Respondent C	○ Pricing is the most pressing concern for the developers we work with, who are usually appointed to carry out a development on behalf of the City ○ Durability of the asset and the building material ○ Maintenance of the assets ○ Operational costs ○ Value-return on investment the City would have after a 50 year lease agreement	Moderate – I know a bit of what is out there		Low – we really could do better than we are right now	Yes, we do consider it, if and when the proposals raise other building strategies. We are also guided by the Climate Action Plan, which governs and gives guidelines as to how far, the City has come., also ensures that the Cty meets the standards that are set in as far as the green building standards are concerned.	No	N/A
Respondent D	○ The norm is such that people typically understand buildings to being bricks and cement ○ Cheaper way of construction ○ People's perceptions ○ introduction to new ideas and concepts	Expert- my job entails looking into all the systems that are being used within the housing industry in terms of integrity and compliance	○ A lot needs to be done; innovative technologies exist but goes mostly unused ○ People innovate the technologies are not marketing them enough ○ Government is not ready yet to receive technology whereas growth needs to be triggered by responsive state innovation and uptake	Low - demand mainly in commercial building markets but not residential development	Yes – As a quality assessor I normally check their specifications, approvals and the systems. In fact, we promote the uptake of innovative building technology and training.	Yes, I work with a range interlocking blocks that have been tested at the centre: Kavango Block Brick (KBB), EEZI Thermal Modular Building System and Hydraform Building System	No assumptions
Respondent E	○ Function- impact on the type of materials that could be used ○ Clients' demands and preference ○ Structural integrity ○ Costs	Not really, I'm mostly exposed to conventional materials	○ I think there are positive moves with good potential to introduce diverse building strategies and thus advance the delivery of social housing	Low - I think we are still struggling.	No- The challenge is most of projects are government projects. So, by the time we get appointed, already there is a professional team that had their architect specify material to be used in the project.	No	
Respondent F	○ Empirically tried and tested products material applications that had been on site ○ Appropriateness: For instance, when we worked on a hotel in Fordsburg the challenge was that the structures were old, as they were built in the 1930s	Expert - My knowledge of materials and different structural and construction	○ More calculated and scientific ○ Has poor penetration in the market therefore it just becomes expensive because very few people are able to serve on the supply-side	Low-	Yes – particularly for walling systems ○ Brick called green light. ○ Polystyrene is very good with installation. ○ Lightweight steel.	Yes, my dad used to work for Ralph Rural Housing Loan fund and I recall a	I questioned the weatherproofing. Familiar with paving appliance.

	○ Thermal insulation and acoustics ○ Conditions of the site ○ The clients' demands ○ Contract period and projected speed of construction ○ Cost implications ○ Certain spaces requirements like fire ○ Heritage aspects	systems is very high	○ Greatest areas of opportunities for shifting mind sets at a wider audience through social housing delivery because of the quantities of roll outs begin to justify the cost in the speed and also in general the crisis that we face is one of an enormous backlog.		AA C block manufacturer and supplies Everett, which is like an aerated concrete block.	time where they were trying to explore in order to push them out into the rural areas.	
Secondary Sources	In the case of non-subsidised housing market, there seem to be an increase in consumers seeking to employ ABMS/IBTs in residential construction due to the long-term cost-saving advantage and being less dependent on the grid (NHBRC, 2020) Subsidised housing consumers related IBTs to temporary housing or low-end housing associated with historically built prefab-type structures built during apartheid times. This is a perception that can be overcome from what the industry refers to as the knock test (NHBRC, 2020) Socio-economic status, affordability of societies (Mpakati-Gama et al, 2012).		Reasons on why suppliers/developers prefer IBTs to conventional building technologies include the following (NHBRC, 2020): ○ Fast installation of IBT system ○ Quality ○ Safer and cleaner building sites ○ Systematic installation of services ○ Less skilled labour required ○ Extra usable space without compromising wall properties ○ 2-hour fire rating ○ Acoustic and thermal performance better than conventional		The Climate Action Plan (COJ, 2021) set out commitment to low-carbon development, net-zero emission and resilient planning		
	Sub- Findings ○ Various aspects are factored into the decision process for appropriate building material in a given project. The variables considered differ depending on the role of the organisation and personal as well as the respondent's position within a project's value chain. This suggests that in order for the diffusion of interlocking blocks to be realised each part of the value chain needs a strategy tailored to address its specific concerns and perceptions. ○ Most respondents are aware of ABMS/IBTs but very limited knowledge on interlocking blocks specifically. While the awareness is moderate, there is still a low rate of the adoption of ABMS/IBTs within the respective organizations and externally by the respondents. The low adoption rate is associated with poor marketing strategies and lack readiness by the government. ○ Commercial and private led developments are seemingly more open minded to exploring the various building materials in the market. ○ Respondents typically held a positive view of ABMS/IBTs. They felt that the housing crisis in South Africa needs as many interventions as possible to reduce the housing shortage.						

4.3 Factors influencing Building Material Selection

The selection and procurement of building materials is an important step which makes a major contribution to the life cycle impacts of a building. Responses from expert respondents demonstrates how the decision is informed by various factors at different levels and by the roles they play in their respective organisations. Figure 11 illustrates the overlapping factors that are often prioritised or considered by the respondents. The responses revealed that cost, durability as well as speed in construction are the three common factors in the process of selecting building materials.

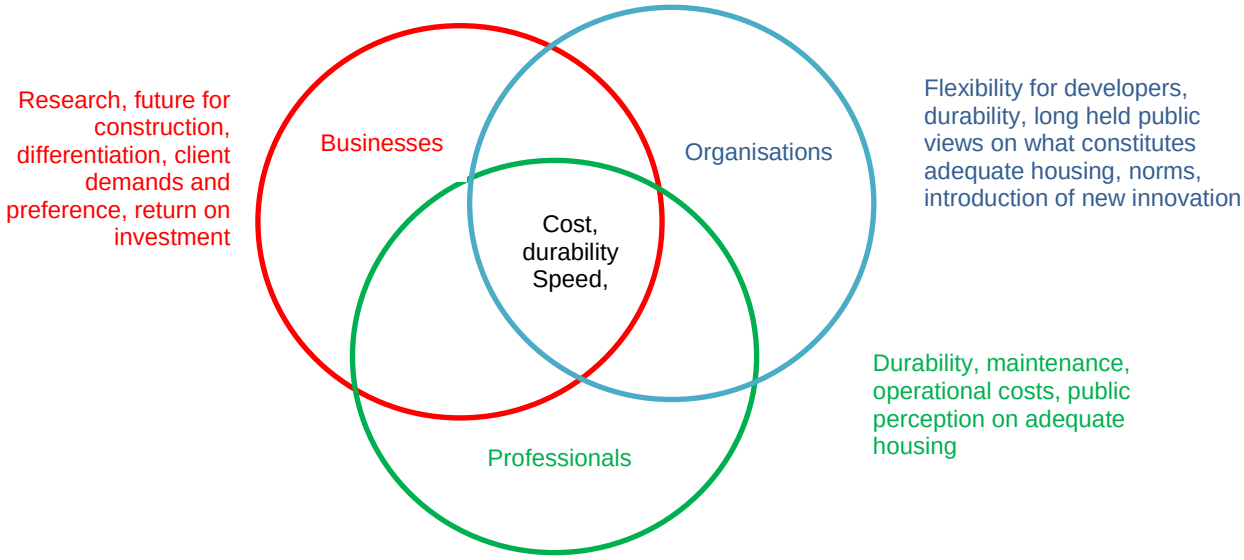

Figure 11: Overlap of factors influencing selection of building materials.

Empirical research which suggests that interlocking blocks are a more cost sensitive option than conventional bricks had an influence on material choice by **Respondent A** and **B**. As their selling point, both respondents confirmed that they do not normally consider other building blocks. Their interest and focus is on the performance of interlocking blocks in the construction market. They also felt that interlocking blocks gave their respective business a comparative advantage over other brick or block suppliers and walling technology in Johannesburg. For **Respondent A**, the cost savings from the use of interlocking blocks was particularly more important for the business to not only offer a unique building strategy in the township but also a financing model. Another selection factor raised was the positioning of the technology with regards to the future of technological advancement in the construction industry, particularly in rapidly growing cities like Johannesburg.

Respondent B asserts that their company offers business-to-business services that supply machinery for enterprises interested in building with interlocking blocks. However, even though they do not typically interact with ordinary home makers as the end-user clients of the blocks, they have found that their customers are typically concerned with costs, quality of bricks, production time, labour costs and exclusivity of the machine. As consistently demonstrated from literature review, cost saving in the use of interlocking blocks is attributable to less use of cement, sand and water. In addition, interlocking blocks do not require paint, and this is often seen as a further post construction cost-saving, similarly to face-bricks which are intended to go without plaster and paint.

Since state organs are tasked with serving the public, encouraging business and growth while ensuring quality of CoJ-owned assets, **Respondent C** insisted that financial viability of developers, durability and long-term operational costs are the top priorities. Financial viability of a project is imperative for developers interested in partnering with the Johannesburg Property Company (JPC) since they have a window of opportunity to make returns on their investment within the 50-year long term lease agreement. This means the value input into building and running the asset needs to make financial sense before they hand over the project back to JPC. Durability and long-term operational costs are considerations that go hand-in-hand because they influence the maintenance costs of the assets. While the JPC also makes provision for operational budget, it is just as important to minimise related costs by all means.

Another factor that **Respondent C** expressed was public expectations of what constitutes adequate housing. This one is particularly important since the JPC-led housing redevelopment project needs to satisfy the criteria of what a liveable home is believed to be, most importantly by its end-users. NHBRC (2020) expresses concern that through the experience of piloting Innovative Building Technology (IBTs) in Gauteng Province, subsidised housing consumers related IBTs to temporary housing or low-end housing associated with prefab-type structures that were built during the apartheid era. However, the report goes further and states that in the case of non-subsidised housing, there seems to be an increase in consumers seeking to employ IBTs in residential construction due to the long-term cost-saving advantage. **Respondent D** from the NHBRC concurs that existing norms and standards influence the way in which people understand the physical look and feel of a home and the prevailing norm in the South African housing market is brick and mortar. Alternative deviation from the combination of brick and mortar is confronted with fear and concerns over inadequacy, possibly due to unproven track record on the ground.

As explained in Chapter 2 (see for example Mpakati-Gama et al, 2012: 268), end-users in most African countries tend to associate, low-carbon materials with low standards of living as they are mainly targeted for the low-income segment of the housing market. This contrasts significantly with the approach in developed countries where low-carbon materials are used for middle to high income housing market.

Responses from professionals revealed that more consideration was placed on the technical aspects, context and client-satisfaction as additional criteria. **Respondent F** emphasised that on the technical aspect he considered building materials that were already empirically tested and trialled in the Johannesburg context, to ensure that there is an adequate understanding of the material. This means that independent consultants are less likely to try out IBTs unless they have seen them being successfully implemented elsewhere and have been in the market for a relatively long period of time. In terms of context, **Respondent F** raised the importance of ensuring appropriateness by making the example of a previous project in Fordsburg where additional heritage considerations influenced material selection process and favoured specific existing materials. The respondent emphasised how existing variables on site also influence the approach and decisions made on how to move forward with a project while ensuring structural integrity of the building is maintained.

As **Respondent F** indicated, thermal insulation and acoustics are also included as factors to consider mainly because comfort of occupants is also influenced by their privacy as well as thermal control performance of the materials selected. These factors speak to limiting sound travel as well as heat exchange between outdoor and indoors, especially through conduction. Optimised design and construction choices should aim at facilitating occupants to rely less on artificial heating and cooling systems through enhancements in passive cooling and heating strategies. On the less technical aspects, client's demand may also force professionals to use a specific material provided they keep the project within stipulated timeframes and projected speed of construction.

4.4 Alternative Building Material and System (ABMS): Awareness, Adoption and Consideration

General perception of alternative building technology is influenced by existing knowledge, exposure and general acceptance of the product in the market. Engagement with respondents reflected a positive outlook on ABMS and green building materials in general. Respondents expressed how the future of the built environment as a whole is gearing towards promotion and use of more efficient and resilient building options and strategies. **Respondent C** indicated that

from his experience, ABMS are typically more precision-oriented which subsequently tends to require more accurate planning and result in less wastage in terms of time and building materials.

Table 10 presents an overview on awareness, adoption and consideration of ABMS where 4 of the 6 respondents felt that their level of awareness and exposure to alternative building materials and technologies was on an expert level and only 2 of them felt they were at moderate level.

Table 10: Awareness levels compared to the adoption rate as well as the consideration of ABT

Respondents	Awareness level			Adoption level			Consideration	
	Low	Moderate	Expert	Low	Moderate	High	No	Yes
A			x			x		x
B			x			x		x
C		x		x			x	
D			x	x				x
E		x		x			x	
F			x	x				x
Total: 6	0	2	4	4	0	2	2	4

However, when asked about the level of adoption within their organisation, with the exception of **Respondent A and B,** other respondents indicated that the rate was still significantly low. **Respondents A** and **B** expressed that their respective businesses are centred on increasing adoption and their vision is to see interlocking blocks and other ABMS become a preferred building choice and tool towards addressing the critical housing challenges facing the country. The other respondents highlighted that there is a significant gap in the rate of adoption within their respective organisations and in the general adoption beyond their companies.

4.4.1 Extent of ABMS Consideration within the Respondents' Role

- Business in backyard housing development

Target market for **Respondent A** are homeowners in townships who are interested in building backyard housing and back rooms for additional rental income using conventional methods and materials. As expressed by the respondent, in terms of demographic profiles, townships are not often exposed to ABMS and interlocking blocks. As a result, they are not aware of the type of blocks that **Respondent A's** company offers and advocates for. Therefore, building confidence and acceptability among homeowners proves to be one of the challenging tasks facing his business. This could also be due to the fact that the client's sole objective is to erect backyard residential structures to earn rental income and is less interested in 'experimenting' with anything

other than what they are already familiar with. This is also fuelled by the absence of successful examples within the immediate vicinity that can be referenced thus contributing to a fear of failure.

- Organisations: Public Entity and Regulator

Given the high level of reluctance to use ABMS by the general public and built environment practitioners, there is definitely a need for public entities to make a concerted effort to formulate and coordinate dissemination strategies to raise awareness. The increased awareness needs to focus on the critical benefits of ABMS to building owners, builders and the public in general. **Respondent C** expressed that the JPC could do better to enhance and promote the adoption of ABMS, especially since there is some level of agency in terms of prescribing the developmental direction towards low energy strategies and building tools. **Respondent C** also stated that at a higher level, JPC is also currently guided by the priorities of the City of Johannesburg (CoJ) Climate Action Plan which takes mandates for serious commitment to low-carbon development, net-zero emission and resilient planning as shown on Figure 12 (COJ, 2021: 68). In particular, theme 2 of Climate Action Plan specifically focuses on optimised energy efficiency in buildings thus setting a pursuit of carbon neutral new buildings that are net zero carbon in operation by 2030 (COJ, 2021). JPC and JOSHCO are among the supporting entities tasked with executing this mandate.

Sub-action	Potential technology	Action type	GHG impact
Implement and enforce the Green Building Policy (from 2021 onwards) and by-law to ensure that new buildings operate at net-zero emissions by 2030. All lines of responsibility must be institutionalised via city systems (KPIs, etc.)	All: efficient lighting, heating, ventilation and cooling, solar water heating, heat pumps, rooftop PV, efficient water devices, insulation, various other technologies in the built environment space		
Develop and implement an awareness-raising campaign on energy efficiency and building codes, targeting property developers and building users.			
Require EUI reporting in all permit applications for new buildings and substantial renovations, and record data for monitoring and sharing with market stakeholders.			
Collaborate with national government and the private sector to develop a national building initiative, including integration of EUI/NZC into National Standards and the development of financial mechanisms to enable a large-scale transformation of the sector.			
Mandate that building design and layout should be optimised for passive heating and cooling by considering the north-south axis.			
Mandate the design of buildings and systems that can be serviced and maintained with local materials, parts and labour.			
Partner with institutes of higher education and non-profit organisations to deliver training programmes on SANS XA (amended), achieving net-zero emissions in buildings and energy modelling to Development Planning, City Power staff and building managers.			

Action type: Enabling Action type: Implementing GHG impact: Direct GHG impact: Indirect

Figure 12: Sub actions aimed at increased efficiency of new public and private sector buildings. Source: (COJ, 2021: 68).

However, in practise, JPC only encourages the use of IBTs to the limited extent of developers being tasked to incorporate it in their development proposals as depicted above. **Respondent C** stated that within a typical call for proposals, the evaluation criteria indicate that proposals must clearly illustrate how the development would address affordable housing needs. Furthermore, there was consideration of sustainability as shown in the extract below (Table 11) from RFP 33/2019: *Request for proposals for the long-term lease and development of erven 1, 3 and 5 Orange Grove*.

Table 11: Showing the requested requirement for development proposals to JPC. Source: (JPC, 2019: 9)

2. DEVELOPMENT PROPOSAL	25	
Conformity of the Development Proposal to the vision for the property as expressed in JPC MBD 12. The development proposal must clearly illustrate how the development would address affordable housing needs (minimum 30% of the whole development, sustainable mixed tenure communities, densification, functional urban design and sustainability (environment and technology) Development Concept **(10)** • Detailed level conceptual design outlining the intended uses, ratios and typologies **(2)** • Integration of multiple uses within the development including parking if required **(2)** • Floor area and elevations **(1)** • Sustainability (Green building elements: modelling and benchmarking of consumption and long term operational costs) **(4)** • Urban form **(1)** Development Programme **(5)** • High level development programme including Inception Stage, Planning, Design, Construction and Commissioning Proposed Rentals **(10)** • Development costs **(2)** • Proposed rentals **(4)** • Return on Investment **(2)** • Respond to target market **(2)** Bidders are to provide the designs that include all of the above in order to obtain full points	10 5 10	**DEVELOPMENT PROPOSAL - JPC MBD 17** **In addition to providing the information on MBD 17, the bidder must submit a development proposal that include all the information as outlined on this page.**

Although such requests for proposals attempt to promote sustainability, the scope is wide and the response is ordinarily limited towards optimising energy efficiency in building with a focus on electricity and water concerns and not necessarily through alternative building materials. Nevertheless, this is a step in the right direction. The green building component of sustainability in such Request For Proposals (RFPs) should be more direct and specific in order to leave less room for distorted interpretation while also stressing the importance of going beyond the usual considerations to create truly low carbon housing with real impact.

Respondent D was a quality assessor for IBTs within the NHBRC who commented on the level of seriousness applied to consideration and increased support for IBT within the built environment. **Respondent D** asserted that the task of the NHBRC is not limited to regulating innovative products and alternative building technologies. (S)he highlighted that NHBRC's Centre for Research and Housing Innovation Department was established for proactive research in the field, inspection and promoting the uptake of innovative building technology and training. **Respondent D** further highlighted that the inspection mandate is targeted at ensuring integrity and compliance

to adequately assist the adoption of the innovation in the market. Despite the fact that there is some level of support, **Respondent D**'s experience reveals that even though there is a wide range of innovative products within the IBT space and even in the interlocking blocks market, adoption rates are still very low, particularly within the residential building market.

- Professionals

Responses from the two built environment professionals indicated a mix of opinions and views. **Respondent F** acknowledged that he considers various walling systems on a regular basis, even though he had not yet had the opportunity to consider interlocking blocks. The different ABMS he has used include a brick called green light - an assembly of polystyrene as a thermal insulator and lightweight steel as well as aerated concrete block (blocks with air-pores which makes them lighter and of higher thermal insulation value). On the other hand, **Respondent E** has some basic knowledge through his own agency. The organisation he works for predominately works on state funded projects and rarely explores ABMS while **Respondent F** mainly worked for private clients.

Respondent F also expressed that while he has had the opportunity to look into some of the options in the market, he has found that commercial and high residential property clients are typically more open minded than the typical homeowner looking to do backyard housing or Residential 1 remodelling. This could be as a result of existing socioeconomic disparities in the context of Johannesburg. Knowledgeable and relatively well-off clients are willing to explore other options in the market whereas poor communities are restricted to what they know because of the stringent budget constraints which discourages experimentation as well as lack of prior exposure to ABMS.

Key sub-findings on sub-question 1 suggest that there is limited awareness of interlocking blocks with the exception of the businesses that work with interlocking blocks and building material regulators. In common construction practice, interlocking blocks are typically associated with paving blocks. However, even though there were higher levels of awareness of broad ideas relating to ABMS, adoption rates in the housing construction market and consideration of options within the market remains quite low. This suggests that there is a gap of opportunity that can be filled to further create more awareness and knowledge on low carbon building materials and technology and therefore increase the adoption rate in both public and private sector developments.

4.5 Data Overview for Sub-Question 2: Contribution of Interlocking Blocks to Low Embodied Energy in Building Construction

This section addresses the second sub-question which focuses on how interlocking blocks contribute to the agenda for reducing low embodied energy in construction building materials compared to conventional bricks

Table 12: Data overview for sub-question 2: Contribution of interlocking blocks to low embodied energy in building construction

	Does this organisation support low carbon development and building materials? If so, how?	To what extent does this organisation prioritise low carbon development?	What is the difference between interlocking blocks vs the conventional bricks?	Are there any environmentally or energy related benefits noted with the use of interlocking blocks?
Respondent A	Yes - our primary business is based on the use of interlocking blocks for the remodelling of backyard housing in townships.	Our of the main objectives is building more liveable housing options for the poor through the use of environmentally friendly building materials, so to a great extent.	○ Promise of 30% cost savings ○ Cost savings calculated differently when compared to conventional bricks ○ People are more concerned with the unit price of a single brick to form the basis of comparative savings. ○ The ability to utilize post construction waste ○ opportunity to reduce the cost of input material ○ Reducing the waste in infills ○ Greater specialisation skills ○ Employment opportunities	○ No firing is required Blocks use less cement ○ Blocks can also be made from post construction waste ○ Ability to produce the bricks on site also means that you can save on transportation cost
Respondent B	Yes – We build the tools that make the production of interlocking blocks possible	It's the primary business	○ 70% dry stacking ○ Weight stabilisation = more support ○ Technology is very friendly – easy building for both women and young adults ○ Thermal properties of the clay- we make use of our sandy loam salt which contains clay, so it helps keep the structure cool in the summer and then warmer in the winter. Plus, their air is constantly fresh. These are like the natural clay properties ○ Better insulation	○ Less cement, labour and time ○ Contains clay which helps build better insulation

Respondent C	Yes - that is something that is considered. I will note the fact that as the city we could do more. However, we do include that element in our tenders.	○ Tender applicants to provide comprehensive plan that will incorporate green building principles ○ We monitor the implementation ○ Benchmark Green Building Council SA guidelines	N/A	N/A
Respondent D	Yes – NHBRC's primary mandate is to regulate and create the best environment for a safe building environment. It's very critical so that we can set the records under standards and know-how and be a centre of knowledge	NHBRC has a research department that focuses on IBT – the testing and support Secondly, we give a warranty cover. We need to make sure that all products built with that system has been done correctly because we are in favour of consumer protection, so we need to understand the product and its integrity in reality.	○ It depends on climate where it's built one can have the same material in Johannesburg and the same material in Pretoria, and they will perform differently due to different climatic conditions ○ Dry construction = saving more time, saving energy and mostly you keep your side very clean like you talked about low budget energy	Depends on whether its clay, cement or both interlocking mix type. The most obvious is the fact that they don't need to be fired. Dry stacking also enables the use of less material and labour
Respondent E	Barely – by virtue of predominantly working on government projects	There is very little An attempt is the way the organisation thinks broadly about safety. View not limited to health but also the conservation of the natural environmental example, trying to maintain or not harm the existing environment: trees, wetlands and streams	N/A	N/A
Respondent F	To be honest, no.	-Every single decision on that is made by an architect. Now you tell me when you're making decisions so minute, would you have time to still consider the sustainability of the source of the products, no	Alternative construction systems are more calculated, scientific, and reduce considerably waste. ○ When you come on site there are usually heaps of sand that have not been used ○ It's much easier to calculate	

		-The appropriate products should be already on the shelves and accessible to the designers - Incredibly stressful job - There is very limited time doing the technical research for green products - Existing businesses are already too invested in the status quo		
Secondary Sources		Gauteng Department of Human settlement attempted IBT (NHBRC, 2020). In the years 2009/2010 Gauteng explored building with IBT through seven pilot projects. Four of the seven projects used Imison Fibrecote as an innovative building material with asbestos roofing and Isofoil inside the roof to improve the thermal efficiency of the house. The other three used Goldflex, Moladi and Robust structures. The table below reflects these attempted projects.	-In most developing countries, like India and South Africa, the cost of executing the project with conventional methods is always cheaper than the cost incurred in adopting emerging technologies due to various reasons such as labour dominated industry with low wages, lack of research and development, logistics issues, lack of congenial relationship between stakeholders, lack of technological advancement in construction and inadequate training of labour for working with emerging technologies(NHBRC, 2020). -The use of interlocking blocks is said to cut the need for manpower by over 50%, leading to a decrease in the level of employment in the construction industry (Nasly and Yassin, 2009) -Identified benefits relate to: use of less cement, cost savings, performance and support (Mali et al, 2018)	-Interlocking blocks require relatively less amounts of input i.e. minimal water usage during the manufacturing process (James, 2021) -Interlocking blocks have a high rate of recyclability can be deconstructed and reused for development again at a later stage (James, 2021)
	Sub Findings: ○ While there are some noted attempts that indicate support for low carbon development, there appears to be very little knowledge around how to practically support the agenda for decarbonising the built environment. There is a need to help organisations bridge the gap between their willingness to support low carbon development and low embodied energy building materials and actually doing it through their respective day to day business. ○ The bottom-line costs of carrying out projects through conventional strategies is still cheaper and viable than going the mile compared to the alternative building materials. This challenges the rationale for the move towards more energy conscious strategies. ○ The value-add contributed from interlocking blocks is acknowledged and understood by well-known interlocking brick related businesses. Other professionals have a basic view on how ABMS as a whole can be advantageous compared to conventional options. ○ Noted a gap between awareness levels versus adoption and this can be associated with: poor marketing strategies, low readiness from government and poor public knowledge around ABMS			

4.6 Positioning Low Carbon Initiative Support

Before engaging on the principal contributions of interlocking blocks compared to conventional bricks, the respondents were asked about the extent to which they promote low carbon development within their organisations and in the work they do. With the exception of **Respondent F,** all the respondents expressed that they were indeed in support of low carbon development as expressed on the data overview table above. However, support needs to be translated to action in order for the goal of creating sustainable and low carbon footprint human settlements (SHS) to be realised.

4.6.1 Hustlenomics Approach- Socioeconomic and Environmental Impact with Interlocking blocks

The Hustlenomics' approach applies an 'innovative shared home financing model' where rental income generated from the completed structure is used to recoup building costs, before the homeowner can eventually regain full ownership of the newly built housing stock. The initial costs borne by Hustlenomics include the cost of municipal approvals, building materials, labour costs, and transaction costs incurred when searching for tenants to occupy the rental units. **Respondent B** asserts that this route creates sustainable rental income for households while creating affordable and liveable rental accommodation for low income tenants. Figure 13 reflects their three-step approach.

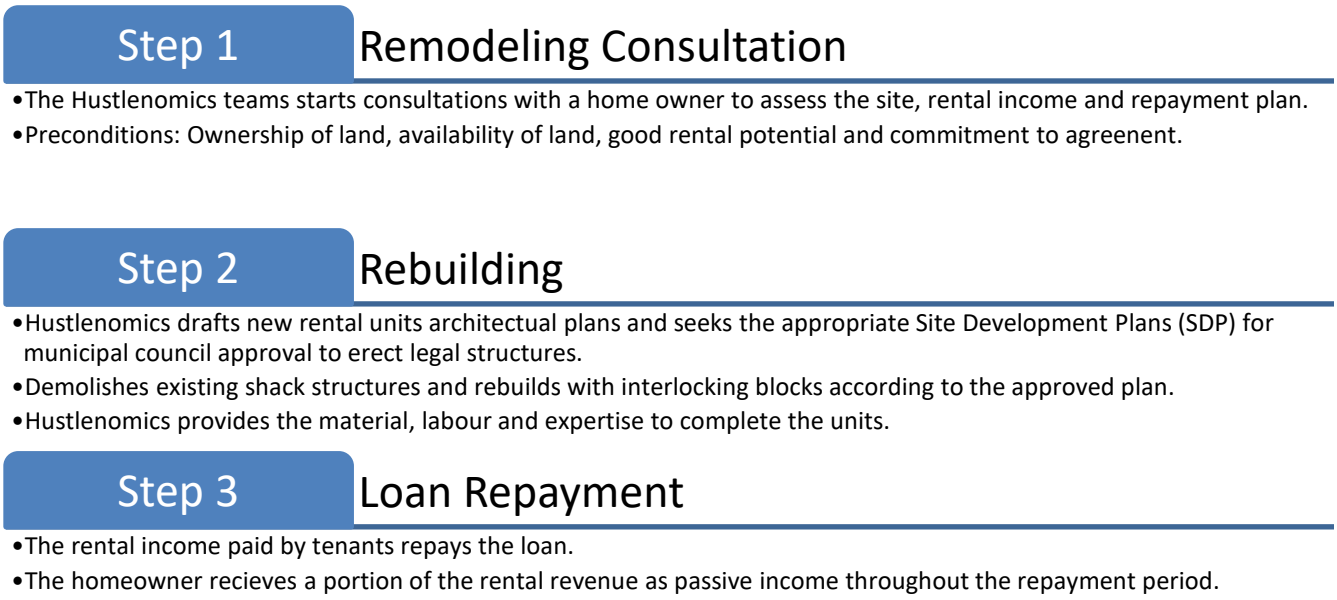

Figure 13: Outline of the Hustlenomics Approach.

Respondent A notes that the remodelling of backyard housing stock in townships is a growing phenomenon with a number of emerging competitive businesses. One of the key factors

underpinning their competitiveness is their use of interlocking blocks and the fact that they offer to build for their clients with their own money at a loan without the use of the homeowners' property as collateral to their contractual agreement. **Respondent A** further notes that people do not want to associate with companies that may potentially put their homes on the line and subsequently render them homeless when the rental revenue does not accrue as projected. This means that all the risks related to collecting revenue from the tenants is left with the company, with very little risk on the part of the homeowner. **Respondent A** states that *"this is an offer a lot of homeowners struggle to disregard. It puts most of the risks on us and is appetizing to the homeowners, particularly those that have a bad credit scoring."*

From their experience, buy-in of interlocking blocks by homeowners lies in eliminating the risks for the costumers. This strategy reflects the confidence level the company has in interlocking blocks. What this also does for the company is that it builds prototypes in which interlocking blocks can be seen in and around the neighbourhood. This passively markets interlocking blocks among neighbours who are also looking to develop their existing makeshift structures to more liveable rooms. Since the use of ABMT such as interlocking blocks is still in the introductory stages, Hustlenomics provides training and employment opportunities to the youth and women in the community. Although fully skilled builders are not required for the use of interlocking blocks or wall construction, some level of training is imperative to ensure that there are no gaps and walls are properly aligned. In other contexts, the use of interlocking blocks is said to cut the need for manpower by over 50% (Nasly and Yassin, 2009).

Hustlenomics also includes the approval process for the backyard housing. The company's ability to navigate town planning building controls with CoJ also strengthens their relationship with homeowners. **Respondent A** further clarifies - *"We have been building back rooms for a long time and our architect found a way to make the shape and form of the backyard units acceptable for Site Development Plans (SDP) approvals while allowing for the adaption to the functionality of the space without making alterations to the structure. Council is less concerned with the functionality and use of the space as long as the built form and appearance of the units are consistent with the permissible uses"*.

4.6.2 Organisation: Excellence in Design for Greater Efficiencies (EDGE) and Warranty

The EDGE (Excellence in Design for Greater Efficiencies) tool was developed by the International Finance Corporation (IFC) which is a member of the World Bank Group. It was established to respond to the need for measurable solutions and to create an evidence-based business case for decarbonizing the built environment (IFC, 2021). One of the notable aspects of EDGE is that it can be used at different stages of a project to certify buildings – from conceptual stages through to renovations.

EDGE is therefore used for rating and certification of residential, retail, educational, office, hospital and hospitality building development that promotes a minimum of 20% less energy, water and embodied energy in materials by choosing more environmentally friendly routes, technology and products (IFC, 2021). According to **Respondent C,** JPC attempts to promote green technology by using EDGE as a guide and benchmark for developments by CoJ. JPC thus uses the guidelines of EDGE to foster low carbon developments for CoJ.

Respondent D from the NHBRC also affirmed that the organisation supports low carbon development by providing adequate support for innovation within related businesses. This was predominately based on the need to address South Africa's housing backlog in a sustainable manner. Additionally, **Respondent D** expressed that the use of NHBRC approved products came with adequate warranty support to ensure consumer protection especially around structural integrity of homes. **Respondent D** further stated that the warranty scheme complied with the Housing Consumers Protection Measures Act and covers major structural defects noted within five years from occupation date.

The sampled professionals expressed that their work paid little attention to the low carbon development agenda as a whole. **Respondent F** stated that he was not necessarily intentional about doing the groundwork related to extending beyond his scope of work to actively change the way he does business. The respondent further mentioned that the architect is already responsible for every level of detail of any project and the task to be intentional about prioritising low carbon development was very challenging especially for a professional working independently. **Respondent F** further expressed that more efforts are required in making the ABMS and IBTs more accessible and better marketed for designers and built environment professionals to easily source the products.

4.7 Benefits: Interlocking Blocks versus Conventional Bricks

One of the research objectives was to bring to investigate the prime difference between the use of interlocking blocks compared to conventional bricks in order to identify the competitive edge associated with the use of interlocking blocks in the Johannesburg context. Respondents highlighted the competitive value of interlocking blocks and added the other factors. As initially noted in Mali, *et al*, (2018), the highlighted benefits relate to the use of less cement, cost savings, performance and support.

4.7.1 Production and Construction Factors: Less Cement in Production Process and Mortar less Assembly

During fieldwork stage of my study, site visit at the Hustlenomics workshop revealed the 5-steps process of making the interlocking blocks as illustrated in Table 13 below.

Table 13: Interlocking blocks production process at the Hustlenomics site

Steps in graphic representation	Steps and Conditions
	1) Soil selection **Respondent A and B** stated that the soil selection phase is important as it affects the quality of the final product. The soil must be free of organic material and should not contain harmful quantities of salt. Soils with a high clay content result to cracked blocks and should not be used. However, when used, they must be mixed with a blending agent (such as sand or quarry dust) and a higher cement content to prevent the blocks from cracking or disintegrating. **Respondent A** sourced the soil from the hardware but indicated that in areas where soil is easily available it may be used.
	2) Stabiliser The most commonly used stabilisers are cement and lime. Cement is best used with soils that have low clay content as it facilitates greater strength quickly. Both **Respondent A and B** consistently stated that the production process of interlocking blocks required less cement than conventional blocks. They further stated that sand and gravel may be added into high clay content soil to increase its density.
	3) Mix preparation This stage entails mixing the filtered soil with stabilisers at predetermined ratios until the mixture has a uniform colour. Mixing can be done by hand or using a mixer. However **Respondent A** insisted that for effective cost savings it is better to use pan-mixer as the labour required to mix can increase the production time and labour cost significantly. Water should be added gradually to the mixture until it is moist but not too wet. The water must be clean and should not contain impurities such as salts, acids, alkalis or organic matter.

	4) Compaction The soil mixture is then loaded into the machine's mould and mechanically compacted to ensure strength and quality. The machines make use of diesel.
	5) Curing Curing is the process of hardening the soil blocks so that they can gain maximum strength. The blocks should be placed on a flat surface with adequate spacing between the stacked rows. The blocks can be stacked in layers of five and covered either with grass or polythene paper to protect from direct sunlight and to reduce the rate of evaporation in order to maintain proper humidity. Curing starts from the second day after the blocks have been prepared. They should be watered every morning and evening for a minimum of 7 days. In hot climates / weather, watering may need to be done three times a day. Full curing takes 28 days for the blocks to reach quality strength of 7-10mpa. The bricks are watered every day and kept under cover in order cure to a minimum stress capacity of 7 mpa.

Interlocking blocks require relatively less inputs such as water during the manufacturing process (James, 2021). In line with Haselau, (2013), the hydraulic compaction of the cement-stabilised soil using the Hydraform machine eliminates the need for concrete or steel columns in the construction of walls of the building. This eliminates 70% of mortar compared to conventional bricks or cement-blocks. The dry stacking process also saves approximately 30% of construction costs and time.

Both outcomes resonate with the recommendation of Nasly and Yassin (2009) that it is in the interest of the construction industry to find time and cost-effective construction alternatives on behalf of clients to ensure that housing is kept at affordable rates. In addition, the excessive use of cement in construction is under scrutiny due to its substantial GHG-emissions and high levels

water required in its production as well as construction processes. Reduction of CO_2 emissions can therefore be achieved indirectly through reduction in the use of cement.

Respondent A asserted that when building with interlocking blocks, 70% of the wall system is dry stacked. An additional benefit of mortarless assembly is the speed of block-laying. The lock system of the bricks makes the process simpler, straight lines are easier to achieve and no setting time is required for the laying process. Both **Respondent A and B** also claim that the visual aesthetic of the blocks is appealing to many of the clients and they do not need any external plastering thus further saving on cement for plaster. Typically, internal walls are plastered to allow for painting of interior wall-surfaces.

4.7.2 Financial Cost Savings

- Promise of 30% cost savings

Respondent A confirms that interlocking blocks are a cost-effective option compared to conventional bricks. Their competitive edge lies on the positive attributes of the blocks and the promise of 30% cost savings which is Hustlenomics' main selling point. This is one of the key aspects that ordinary people find hard to comprehend. Typically, people are more concerned with the unit price of a single brick to form the basis of comparative savings whereas interlocking blocks become a saving option when looked at as a whole from raw-materials to completion of the house. This also points out to the lack of information within the building sector which in turn undermines the basis for cost comparison among other factors of interest to the owner.

Respondent A therefore notes that this is why the potential cost savings is seen and calculated on the basis of the full process, from production to finished project and not solely on the unit price of an individual block. This contradicts the typical claims from secondary sources such as Wazir *et al* (2014) that have observed that in developing countries the cost of executing a project with conventional methods is typically cheaper than the cost incurred in adopting emerging technologies due to various reasons such as labour dominated industry with low wages, lack of research and development, logistics issues, lack of congenial relationship between stakeholders, lack of technological advancement in construction and inadequate training of labour for working with emerging technologies.

Respondent A shared the drawings (Figure 14) and Bill of Quantities (BOQ) (see Appendix 4) for the Ivory Park project in Soweto which the company is currently (2021) working on. The project

entails the redevelopment of existing shacks as backyard housing. The total cost estimate quoted for the project was R190 849, 80.

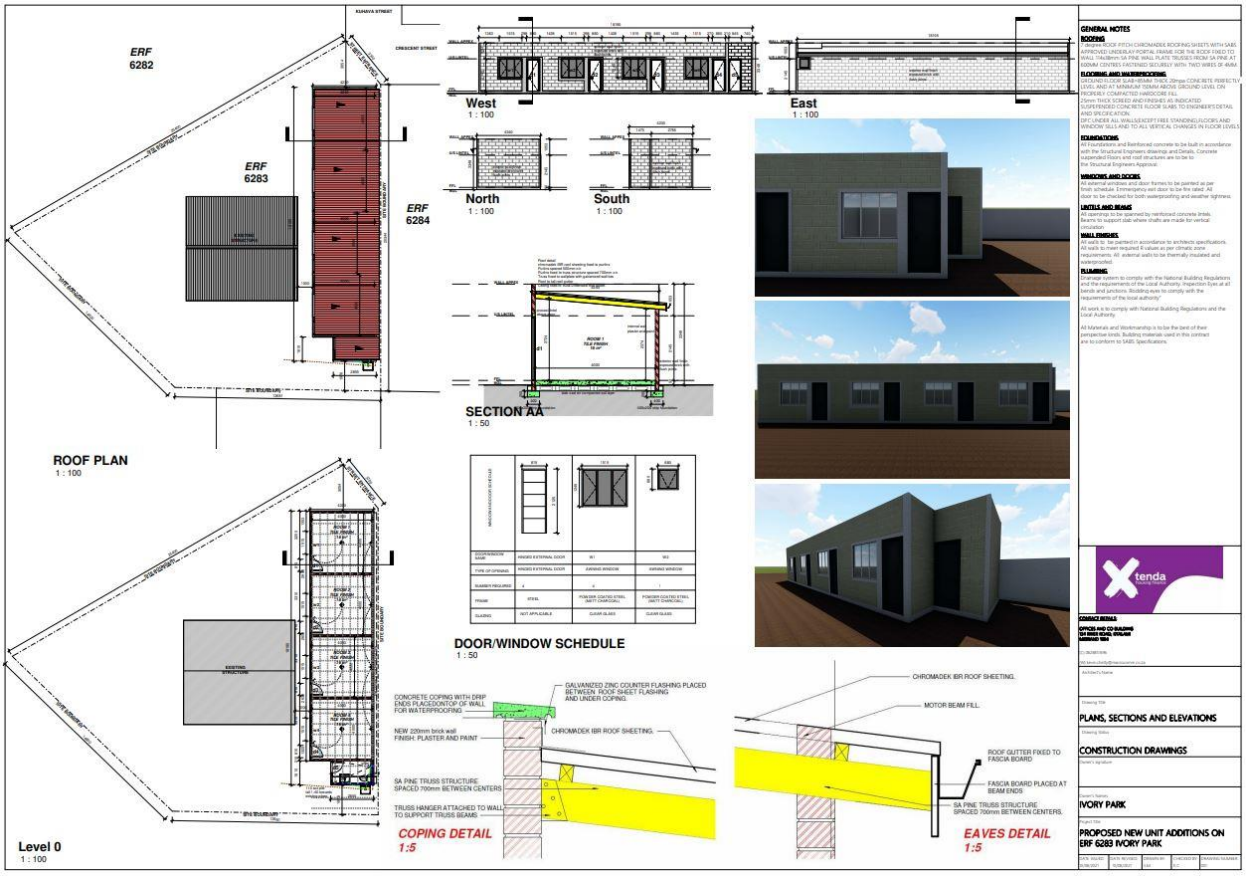

Figure 14: Site Plan of Hustlenomics' Ivory Park project. (Source: Respondent B)

- 70% Dry Stacking

Respondent B stated that, through the use of interlocking blocks, approximately 70% of the structure is dry stacked (with the exception of the foundation portion and floor slab). This further reduces the use of cement as plastering is not necessary. Dry stacking works in a similar manner to lego building blocks, which means that developers can build with increased speed and this eliminates the time required for mortar to cure when using conventional bricks. The ease of dry stacking also makes the building strategy friendly for women and young adults. Hustlenomics' workforce is testament to this benefit as it includes young women as well. Through the elimination of plastering the team financially saves on plastering material, labour required for plastering as well as time spent on the project. **Respondent D** expressed that the NHBRC has assessed and listed a range of certified interlocking brick systems in the South African market which thus

demonstrates various options towards reducing project completion time as well as significant savings in costs and embodied energy.

4.7.3 Performance Indicators: Brick quality and Compliance

Structural performance of interlocking blocks and other ABMS is one of the most critical considerations. **Respondent B** claims that interlocking blocks have a higher density than conventional bricks and this gives the structure more load bearing capacity and improved water resistance. The respondent also argues that the high density and thermal properties of the interlocking blocks provide better thermal- mass by keeping cool inside during the day and warmth at night due to thermal-mass of the structure. Consistently, Bredenoord (2017) observed the experience of interlocking blocks in Uganda and found that interlocking blocks created thermal mass which moderated indoor temperatures thus reducing heating and cooling costs.

Acceptable performance of building materials is benchmarked against values and compliance guidelines set by diverse compliance bodies in the sector. According to **Respondent A and B** such performance-based indicators and certification are necessary in the absence of ABMS codes and standards because they help build trust between professionals, clients, developers, investors and financial institutions. They certify that the products are compliant with industry standards.

Figure 15: The various institutional certifications awarded for Hydraform Source: (Hydraform: 2021, 1)

- Agrément Certificate Requirements

One of the key certifications body is the Agrément Certificate which is defined as “a certificate that confirms fitness-for-purpose of a non-standardised product, material or component or the acceptability of the related non-standardised design. The certification conditions issued by the

Board of Agrément South Africa" under the National Building Regulation and Standards Act, 1977 (Act No. 103 of 1977). It entails the testing of non-standardised products or alternative building materials against performance-based criteria such as structural strength and stability, water penetration, durability, behaviour in fire and thermal performance in order to determine their fitness-for-purpose (De Villiers and Boshoff, 2012). Agrément allows and encourages for the testing of new and sometimes greener products and materials in order to curtail underperforming or substandard products in the industry.

- NHBRC Approved Certification

The compliance of Hydraform with NHBRC standards as an Innovative Building Technology (IBT) encourages the diffusion of interlocking blocks. It further confirms the noted benefits discussed above. NHBRC approval means that interlocking blocks have met the satisfactory performance requirements for structural strength, stability and material behaviour in case of fire, moisture exposure and storm water resistance. In relation to structural integrity, **Respondent D** from the NHBRC raised the fact that context was also an important consideration to quality and performance of interlocking blocks. He further stated that NHBRC has a database of certified products and the Kavango Block Brick (KBB) which is also a form of interlocking blocks, experienced some challenges in the Western Cape, which was different to the experiences of the same product in Pretoria. **Respondent D** stated that the coastal weather conditions and high humidity impaired the shape and form of KBB interlocking blocks but they were found to perform better in the dryer regions of the country. The assessment and certification of IBTs is critical and demand adjustments to guidelines on the use of specific material per region across the country based on their behaviour patterns (performance) within specific geographic regions.

- Concrete Manufacturers Association (CMA) Special Commendation Award

Beyond the certification, Hydrafrom's use of interlocking blocks in the Radway Green Project in the Eastern Cape was recognised for community uplifting in 2016. The CMA initiates standards in close cooperation with SABS in developing new precast concrete products.

4.7.4 Environmental Factors: Post Construction Recycling

- Questionable performance and quality of product

Durability is one of the set criteria for Agrément certification. James (2021) notes that Toughie interlocking blocks (a brand of blocks developed in Ernakulam, Kerala - India) have a high rate of recyclability and can be disassembled and reused for another development on the same site or

in a different one. **Respondent A** conceded that the ability to allow the re-use of post construction waste is one of the best attributes of interlocking blocks. **Respondent A** uses construction rubble as raw material when producing new blocks. This is a great opportunity to reduce the cost of input material while reducing the waste that goes to landfills or illegal dumps in open spaces. The only challenge related to the reuse of post construction waste is that the quality and colour of the blocks cannot be consistent because of the diverse range of input materials. To overcome this challenge, **Respondent A** encourages the use of rubble based interlocking blocks for the foundation as well as the internal walls (which can be plastered) if the homeowner does not like the appearance of the rubble blocks on external walls.

4.7.5 Local Machinery Support

Respondent A also advocated for the use of locally produced machinery as it allows for further post purchase support. **Respondent A** expressed that the additional support offered by Hydraform has helped him with building a wider network with other builders. The local support has also made it easier to source additional parts or dealing with maintenance challenges, particularly during COVID –19 restrictions which would have made it harder to get parts abroad if he had sourced the machinery internationally. **Respondent B** stated that Hydraform has training sessions for all their customer base and they formed a WhatsApp group where all the businesses in other areas are a part of the network.

4.8 Sub-Findings Relative to the Sub-Question

This chapter has presented data, analyses and sub- findings based on interview responses from purposely selected respondents. Clear levels of awareness and interest was noted across the respondents. Their' levels of awareness and interest was found to be informed by their backgrounds, knowledge and long held views and perceptions on building materials. The outcomes of the fieldwork also clearly demonstrated affordability and quality through a niche market developer within the backyard redevelopment of rental shacks for homeowners in Soweto. The use of interlocking blocks systematically demonstrated benefits of aesthetic quality, cost reduction and time saving in construction stage.. Hustlenomics' experience also demonstrated the opportunities for recycle of construction waste and ease of construction which allows engagement of women and less skilled youth. Another sub-finding was that there is clear institutional support with regards to quality assurance through certification. Lastly, it was noted that the bottlenecks hampering the diffusion of interlocking blocks and other ABMS

exist at different points along the supply chain - from procurement through operations management to the consumer downstream.

Firstly, in response to the first interview question, most respondents emphasised that there are not enough guidelines and incentives that strategically promote the use of low carbon materials. Existing public entities responsible for development of human settlements need to actively promote the adoption of ABMS. Secondly, there are a number of factors that influence how businesses, professionals and end users perceive low carbon ABMS. These include superficially derived cost implications by consumers or clients (such as by comparing brick solely on the bases of brick unit prices instead of looking at the process holistically). Long held views and the propensity to gravitate towards what has been tried and tested, durability and other qualities mentioned also add to the continued use of conventional bricks. Lastly, even though most of the socioeconomic and environmental benefits are well-documented and supported by public entities and businesses, at least at a theoretical level, the uptake remains relatively low. This will be explored further in the next chapter along with corresponding recommendations towards improving adoption.

CHAPTER 5: ADDRESSING THE BOTTLENECKS HAMPERING THE DIFFUSION OF INTERLOCKING BLOCKS

5.1 Introduction

In 2017, the then Minister for Public Works Nkosinathi Nhleko called on the construction industry to embrace innovative technologies that have superior energy efficiency performance compared to conventional materials. The Minister stated that *"energy efficiency will contribute to sustainable development, while eco-labelling construction products, will contribute towards South Africa's green building policy,"* (SA News, 2017)

Taking the necessary actions to mitigate negative impact on climate change by the construction industry and increasing the use of energy efficient building materials is constantly expressed as a national priority, among other competing demands. This is expressed in policy and to a less extent in practice. This is due to the fact that embracing ABMS would not only be an environmental concern but also an imperative for socio-economic justice (CoJ, 2021). The extremely low adoption of ABMS therefore calls for an understanding on the challenges hampering this move towards a more sustainable approach as a prerequisite towards determining possible action to achieve the City's goal of net-zero emissions by 2050.

This chapter responds to the third and fourth sub-questions on identifying key barriers to the diffusion of interlocking blocks as well as possible strategies on addressing the barriers.The first section presents data and analyses on the challenges that hinder the diffusion of Alternative Building Materials and Systems (ABMS), with specific reference to interlocking blocks, in the housing construction sector. This is based on views and perceptions expressed by experts and industry participants in response to interview questions. The second part articulates responses on strategies that may assist to overcome the identified barriers. Similar to the previous chapter, primary data were sourced through interviews and secondary data were abstracted from journal articles and industry reports.

5.2 Data Overview for Sub-Question 3: Barriers to the Diffusion of Interlocking Blocks

This section addresses the third sub-question which focuses on identifying and discussing the key challenges to the diffusion of interlocking blocks in the residential development sub-sector of the construction industry.

Table 14: Data overview for sub-question 3: Barriers to the diffusion of interlocking blocks.

	What challenges does this organisation/company face with regards to prescribing low carbon construction materials with a low carbon footprint?	How accessible are interlocking blocks and other innovative building materials?	Are there any challenges to their accessibility in the mainstream market? If so, what are they?	What are some of the challenges that professionals face with regards to designing, specifying and managing the use of green building materials?
Respondent A	○ The machinery is expensive – you are looking at approximately R120 000.00 to function well with the required accessories ○ Brick modification needs specific tools- you can't just break the bricks to modify the shape or form as you wish with ease ○ Quality Assurance - You also need a brick tester to ensure that the quality of the bricks is as good as prescribed ○ Target market: not informed ○ Requires semi-skilled labor ○ The adoption of green building materials like interlocking blocks are not found in the typical hardware like Builders Warehouse, Cashbuild and Build-It	Not easily accessible - Interlocking blocks can be kept and stored in a hardware like any other building block. You can also keep an inventory of the interlocking blocks and keep them on the pallets as well. However, this is not done	Hardware store sales managers are about making shelve room for products that are already known, wanted and marketed as well as easy to use. As a result, sales managers are typically reluctant to include emerging products as it is assumed that they may spend more time on the sales shelves that existing products. Interlocking blocks are still unknown and are currently not in demand. They also require specific skills and understanding of the fundamentals	○ Taking on the risks related to the innovative product ○ Building awareness with clients and encouraging the use of ABMS. ○ Clients typically already have a picture and price estimates of what they are looking for. It is very hard to suggest something that they have not seen before
Respondent B	Hydraform's primarily offers a range of interlocking block machinery for producing the blocks. The challenges noted are those experienced in the sale of machinery and those expressed by developers that purchase interlocking block machinery from Hydraform, these include: ○ Stereotyping: Questioning if the bricks will even stand. So that means that all parties - those that sell the machinery, sell the interlocking blocks and those that use interlocking bricks - are by virtue involved in addressing stereotypes and educating others. ○ People are not well informed.	Not easily accessible	○ There are only a few actors in the space of providing machinery and promoting alternative building technology ○ Exclusivity/ patency	○ The challenge of convincing clients that alternative building materials are the best option, without having been exposed to them long enough to know if they will still be as good in the long run. ○ Limited level of awareness of the general public.

	○ Dominance of existing companies. ○ Life span – Company hasn't been around long enough to have proven durability. People tend to be concerned with proven life span of the bricks.			○ Introducing green building material requires one to firstly train people/staff on the products, which translates to more work. Alternatively, an employer would have to source people with specialised skills with adequate knowledge of the green products, which also translated to more money coming out in the form of remuneration.
Respondent C	○ Government on all levels is good at talking the talk, but not implementation initiatives ○ Johannesburg as a metro municipality has access to enough information out there However, environmentally geared strategies fall at risk of being tick box items. ○ Low hanging fruits approach to initiatives ○ The value of such efforts is not directly or explicitly expressed for people to buy into the vision, both government workers and the general public we serve. ○ The mammoth task is carried by few actors ○ If value can be sold, and perhaps I don't know more education, I guess so that the task of promoting better practice and low carbon development would be tackled from all departments and not be the burden of specific units and each unit would establish the role they too could play in fulfilling it ○ This action aims to improve the energy efficiency of existing buildings using technologies, limited to addressing aspects which include efficient lighting, heating, ventilation and cooling, solar water heaters, heat pumps and rooftop PV as opposed to building material	Not easily accessible	○ Products are hard to source locally for developers ○ Inadequate demand to meet the supply	
Respondent D	○ Systems and service providers come with innovation and when challenges occur relating to: poor marketing, awareness or training or lack of understanding or disinterest by the prospective clients ○ Resistance to change from the public as people deem technology as expensive	Not easily accessible	○ I think the challenge is because mostly are licensed and the service providers want to keep the license to themselves. Nobody gets to know about these products	○ Authorities that are introducing this legislation are not supporting it, that's the biggest problem ○ The government has a policy and has joined the international

	○ NHBRC only regulates, support and promotes the uptake but it doesn't build and develop ○ Service providers introduce a material, get a certificate and build the targeted project, and then the material gets archived with all the other shelved technology and innovative systems. As a result, no one gets to know about the technology, so it becomes another problem. This means that it is often used for experimentation without a proper plan to further disseminate or introduce to the wider market ○ There aren't any role players within the spheres of government professionals who are also to an extent, proponents of IBT come to introduce one house and then disappear ○ So, most of the system providers don't renew the license. They introduce a material, get a certificate and build that targeted project, and then after the targeted nothing		unless they are displayed and marketed in public stores and hardware's	community, but they're not building with adequate support of the existing innovations
Respondent E	○ Our work is directed by the client. Currently the way we do business is conventional	At this point, I don't think so	There's less of these materials on the market. I think that is driven by the supply and demand. So, the suppliers now can't be ordering so much of that material when there's not so much demand of it out there	Pushing suppliers to get more
Respondent F	○ The status quo works and is profitable_- difficult to change as everybody in the value chain has invested money in things working this way ○ Existing models are proven and tested blueprint_- Changing their variables reduces predictability and required a different/more skilled workforce/training for the use of alternative building materials & systems ○ Bearing the risk - as a professional architect, I have a fiduciary responsibility to my client I have to protect their investment by law I have to give them the best advice I can	Not easily accessible	○ They don't really become a range of choices for developers to even consider, so when it's not on the table, not on the shelves ○ Ordering them from overseas has enormous waiting periods. Professional bodies to do more than seminars.	○ Very low skilled construction labor Illiteracy with regards to the role of built environmental in the sustainability agenda Clients' comfort zone - very difficult to convince History of resistance with big institutional bodies/government - mistrust on ability to govern
Secondary Source	(NHBRC, 2020) ○ Limited detailed knowledge on the availability, costs, performance, maintenance costs and longevity of IBTs ○ Beneficiaries highlighted the difficulty for alteration once the building is complete			

	○ Public sector (Authorities, Government and Implementing Agencies) knowledge was still at infancy ○ The scarcity of materials was also somewhat a factor since the building innovations were being introduced into the market ○ End-users remain largely suspicious and distrustful about the IBTs ○ Contracting and maintenance is constrained by the predominant business model, i.e. franchising. (Intellectual Property (IPs) controlled by a few licensed Service providers (SPs) and some are external) ○ There are limited contractors that are registered/ Licensed to construct using IBTs. In most cases, existing conventional contractors are not in a position to independently undertake construction of IBTs ○ Quality assurance is critical- the NHBRC needs to assist in this regard so that our inspectors are able to quality check the different innovative technologies for compliance ○ The costing aspect of IBTs is elusive			
	Key sub-findings: ○ Both technical and political considerations influence decision-making in the urban geopolitical space. This inability to achieve both just and sustainable outcomes is not necessarily reflective of a lack of will, or even the lack of explicit strategies to foster these imperatives, but rather the result of a complex set of factors and trade-offs at decision-making. Conventional wisdom and assumptions need to be challenged to change the status quo. A number of respondents have expressed the need for this, as their efforts remain unmet with incentives and supporting programmes ○ Importance of exploring how conflicting rationalities are debated and dealt with, not only to build a more in-depth understanding of real conflicts, but also to expand imaginations around how such conflicts could be dealt with. Here an analysis is called for, not merely of the differences in perspective but also the underlying power, politics and cultural factors that build different perspectives ○ Noted poor accessibility of IBTs in the mainstream market place. The inaccessibility of IBT was related to poor public perception and poor marketing strategies ○ Noted a mix-match between policy and practice: The municipality has various strategic policies that reflect commitment to the agenda for climate change action. However, procurement and tender processes do not reflect the strong intent ○ Government does not incentivize the use of IBT to respond to the existing commitments towards the net zero agenda in development proposals ○ Noted more efforts required in building professionals' confidence in using ABMS ○ Lack of meaningful support of the IBT and ABM niche market			

5.3 Barriers to the Diffusion of Low Carbon Construction Materials – Case of Interlocking Blocks

5.3.1 Low Accessibility: Mainstream Market Adoption is Slow

Mpakati-Gama *et al* (2012) notes that accessibility and availability are critical factors influencing the choice of products and materials used in construction. For example, looking at a different context in sub-Saharan Africa and analysing the use of traditional, conventional and alternative materials, Mpakati-Gama *et al* (2012: 267) established that the *"increased distance from sources of traditional building materials fueled the use of conventional materials for urban housing development in Dar es Salaam, Tanzania"*. This denotes that developers and clients are most likely to opt for products and materials that are easily accessible and within close proximity.

On basis of primary data, **Respondent A** noted that the adoption and accessibility of interlocking blocks is limited as they are not found in typical local hardware stores such as Builders Warehouse, Cashbuild or Build-it. **Respondent A** indicated that hardware stores are more about availing shelve room for products that are already known, wanted, marketed and easy to use. This is done to ensure that the products get purchased and leave the shelves quickly. However, interlocking blocks are still unknown and therefore not necessarily in regular demand. Over and above these drawbacks, they require specific skills (acquired through training) and an understanding of some basic fundamentals in construction. Both literature and engagements with **Respondent A** and **B** indicate that while the use of interlocking blocks can be user-friendly when building, the process of making the blocks required some training even for semi-skilled bricklayers.

Beyond the challenge of accessibility, respondents felt that ABMS are not readily available for use by developers and for this reason they tend to avoid them, especially when working on stringent project budgets and timeframe. **Respondent F** extends the argument by stating that due to low accessibility and availability in the mainstream chain stores, some ABMS are sourced abroad. Not only does this require additional research for performance warranties but also means that professionals run the risk of further delays in project duration as shipment can take more than the projected time. This was the case during the COVID 19 pandemic hard lockdown, as import and export products were delayed due to imposed travel restrictions.

Respondent B also stated that patents and intellectual property (IPs) reserved on specific ABMS products and services challenge the growth of the industry and further constrains accessibility. While copyrights and patents are critical for protection against fraudulent duplication, it hinders

the advancement of ABMS related products. In the same discussion of exclusivity and specialised skills, NHBRC (2020) also found that there are only a limited number of contractors registered or adequately licensed to build with the use of specific ABMS. Conventional contractors are not necessarily in a position to independently undertake construction with ABMS and this typically builds concern regarding quality as well as follow-up maintenance. This presents a conundrum because reducing the levels of restrictions as a potential response might open the market to ill-equipped chance takers to enter the market and produce substandard products through fraudulent duplication.

5.3.2 Inadequate Knowledge and Perception

In consistence with Section 4.4 on relationship between low adoption and low levels of awareness among clients and general public, HNBRC (2020) also notes that beneficiaries of the Gauteng Department of Human Settlement (DHS) pilot projects had limited knowledge on IBTs. The availability, costs, performance, maintenance costs and longevity of IBTs were all grey areas that needed to be filled. As a result, end-users remain largely doubtful and skeptical about the IBTs. **Respondent A and B** noted that misconceptions on ABMS such as interlocking blocks pose as a disadvantage and further adds that poor knowledge of dry stacking resulted in potential users being concerned about stability and weathering.

Respondent F observed that intertwined with inadequate awareness on ABMS among the general public, a sense of fear and resistance to change is also noted when suggesting green products and building materials, particularly in township areas. **Respondent F** alluded to the distrust in previously marginalized communities which is intensified when proposed change emanates from external actors or the state. They often refer back to the country's historical apartheid regime with cases such as the matchbox houses constructed using the hazardous asbestos roofing which was later found to cause adverse health effects to the extent where its use was banned, but its impacts on residents of prior developments continues.

5.3.3 Economic Factors: Expensive Machinery and Accessories

In line with sub-findings noted in Section 4.4, cost is the most consistently highlighted factor in influencing choice of building materials. While cost is a critical factor, it is only partially understood with regard to ABMS in comparison to conventional materials. On interlocking blocks specifically, **Respondent A** and **B** acknowledged that the machinery is expensive compared to conventional brick making machines. A standard Hydraform machine which functions well with the required accessories (see Figure 16) costs approximately R120 000. With adequate labour force, entry

level Hydraform machine can produce 500 blocks a day which translates to 1 block every 15 seconds. In contrast, a conventional brick making machine costs around R15 000 but can only produce 6 to 12 maxi blocks at a time. This translates to about 200 per day.

Figure 16: The cost and features of an electric Hydraform block making machine Source: (Hydrafrom, 2021:1)

In addition to the basic compressing machine, additional accessories are needed for quality control and brick modification as well as specific moulds. This explains the price difference between the costs shown in Figure 16 versus the egg-laying block making machine. For instance, interlocking blocks cannot be simply broken down in order to get smaller parts to go where a full block would not fit. Instead, a specific block cutter is required to appropriately modify the shape or form with ease. Each shape needs to be carefully produced with its particular mould because the dimensions need to complement other blocks appropriately. This correlates to NHBRC (2020) findings among beneficiaries which highlighted difficulties in alteration for ABMS once the building has been completed.

With regards to consistent quality assurance, **Respondent B** stated that interlocking block builders also need to regularly test their blocks using a block tester. While the additional accessories reduce the labour required, they are still relatively expensive. For instance, one can manually mix the input materials but that is a labour-intensive exercise. To make the relationship between labour and production costs one needs to produce a minimum of 1 500 blocks within an 8-hour day. So, a pan mixer is required for this process, which would not normally be a requirement when making conventional blocks.

5.3.4 Does The Status Quo Work?

While most respondents concur that proceeding with business-as-usual basis is not a sustainable option, **Respondent F** contends that one of the challenges for the increased uptake of low carbon

building materials is the fact that the current ecosystem of the construction market 'works' and remains profitable for many actors involved. He further stated that businesses in the value chain have already invested into the existing models and without a mandatory expectation to alter the way things are, the envisaged change will not take place at an acceptable scale. **Respondent F** further made the example of Baldwin Properties, highlighting that the similarity (built form, design, building materials, style and density scale) of their residential properties across the country suggests that the business has carefully developed its overall development model. A model that has been tested and modified over several years which makes it difficult to adopt alternatives which would take a while to dovetail into their residential development model.

Respondent F also emphasised that design professional teams typically develop a signature of their development to differentiate and market their brand but also most importantly to reduce the time spent making decisions on factors that do not warrant further consideration. These include table counters, finishes, foyer designs and building materials. Further to this, **Respondent F** mentioned that even as an independent architect, he also already has set spreadsheets he has developed over time to rationalise the amount and price of building materials required per square meter of various building types. Given such constraints, there is hardly any incentive for organisations and professionals to change the variables of their existing models, especially when low carbon building materials remain less accessible. For existing businesses such as **Respondent F**'s practice, considering alternatives would mean discarding a "working formula" (unsustainable conventional methods and materials) for collective values and benefits (sustainability through the use of ABMS) which often requires businesses to risk tampering with their profit margins for little to no institutional or market incentive.

Respondent E expressed concern that, relatively new ABMS entail a critical risk for professionals. They made reference to the fact that these products are manufactured and tested in one context, then bought and utilised to construct building materials in another. The place of manufacturing and place of construction have different environmental/climatic and spatial conditions and attributes, which may yield different results with regards to the durability and robustness of the product. NHBRC (2020) also noted that there are limited contractors registered or licensed to construct using IBTs. In most cases, existing conventional contractors are not necessarily competent to independently undertake construction using IBTs. Aligned with the fear of bearing the risks, **Respondent F** brought to light that professionally registered architects are mandated to provide their best advice on product selection and can be held legally liable with specific penalties if a structure is not in good standing. With the legally binding agreements

commonly used in the sector, **Respondent F** does not feel secure recommending the use of products that have not been in existence for longer than 40 years, which is an appropriate life span for materials to be deemed durable in the industry.

5.3.5 Policy and Practice: Procurement and governance

NHBRC (2020) argues that knowledge of ABMS among public sector authorities (government and implementing agencies) is still at infancy and this stalls the planning, management and implementation of ABMS in public funded projects. This further impacts the capacity to plan and manage the implementation of IBTs irrespective of the national policies set to guide and foster development towards green infrastructure and energy efficiency in construction and other sectors as highlighted in Chapter 2 (see Section 2.3).

In addition, **Respondent C** highlighted that the directive for climate change action is clearly outlined in local government policies as well. Although **Respondent C** expressed that CoJ has specific policies to guide high-level approach and developmental direction, translation of the set goals into implementable actions, especially through construction projects, calls for further facilitation. **Respondent C** also articulated that there is a significant gap between what is possible versus the evidence on efforts with regard to prioritising low carbon development, specifically low embodied energy building materials. The rationale as articulated by **Respondent C** included the following critical factors:

- **Poor and reactive governance:** The challenge of poor governance cuts across all government levels and not solely within CoJ. **Respondent C** felt that emphasis is placed on creating policies and theoretical strategies with extremely limited understanding of how such policies are translated into action on the ground. Government typically focuses on low hanging fruits, as opposed to complex challenges like decarbonizing the built environment. However, this approach is fueled by focus on other pressing needs and concerns such as the supply of basic needs such as electricity and water. While the two concerns can be integrated towards the challenge of sustainability, prevailing emphasis is primarily geared towards addressing immediate socio-economic pressures. The relationship between the state and its people is one where results and outcomes need to be visible and unfortunately the outcomes of targeting action towards low carbon development is not easily calculated, measured or even displayed. However, the positive effects that may be experienced in the long run are invaluable both to sustainability of the natural environment as well as social wellbeing of citizens.

- **Procurement flexibility:** calls for development proposals are a give-and-take opportunity for business growth and opportunity to develop ways in which the CoJ can increase its asset register through private-public partnership in the form of long-term lease agreement. Given the above premise, the development opportunity still needs to be attractive for developers. As demonstrated in the previous chapter, Requests For Quotes (RFQs) tend to provide guidelines and recommendations that are open to interpretation and thus allow developers to choose how to demonstrate sustainability of their developments. As a result, this is often done in the form of tick box approach which is limiting.

- **Questionable environmental value:** environmentally geared strategies are at risk of being translated into tick box exercise in developing cities. The value of such efforts is not directly or explicitly expressed in a manner which encourages actors and stakeholders (both government officials and the general public) to buy into the vision which underpins such strategies. This could be due to the fact that environmental value of ABMS is still something that is questionable and seems to be only feasible on paper, as there are not many successful examples that can be referred to in the local context, especially where medium to high density residential development is concerned.

In a similar line, **Respondent D** highlighted that one of the fundamental challenges is that while government and local authorities are putting in place the necessary legislation and regulations for innovation in the built environment, they do not fully appreciate the opportunity for related benefits of IBTs through government funded projects. The delivery of state funded social housing and affordable rental stocks is a potential instrument in the promotion and support of existing innovations which include interlocking blocks. For instance, the Johannesburg Social Housing Company (JOSHCO) received a total of R321 million in CoJ's 2018/2019 financial year, as it is tasked to be CoJ's vehicle for the delivery of social housing and management of the rental housing stock across the city (JOSHCO, 2020). While JOSCHCO claims to actively support development goal 2 of the Growth and Development Strategy (GDS) 2040 (provide a resilient, liveable, sustainable city pinned by smart infrastructure supportive of a low carbon economy) outputs and strategic outcomes demonstrate minimal progress or contribution to the goal or its targets. JOSHCO's strategic response in the pursuit of the green agenda is limited to installation of solar systems in all projects, water harvesting systems and rooftop gardens. Such a narrow

interpretation in response disregards the opportunity that lies in the consideration of IBTs and responsive selection of building materials.

5.3.6 Certificate Requirements and Intellectual Property Protection (IPP)

The Agrément Certification is both a pro and con in the sense that as it protects both the builder and user from the use of flimsy or below standard materials, it also poses other challenges that may contribute to the slow diffusion of ABMS. As De Villiers and Boshoff (2012: 10) notes, certification costs of an unconventional or innovative building material/technology by Agrément can amount to *"R300 000 and it can take between 3 months and 3 years to complete the process, from application to issuing of the final certificate".* **Respondent D** from the NHBRC concurred by stating that both the certificate requirement as well as the IPP also play a role in limiting the uptake of IBTs and alternative building materials. **Respondent D** further mentioned that many system providers do not renew their licenses due to the prohibitive costs for renewal. The typical practice is that system providers introduce a specific material, get the necessary certification and build a targeted project. Thereafter the system is shelved. This means there is limited appetite to further disseminate the product or push for its availability and access in the market even among the business owners themselves.

Shelved ABMS causes further drawbacks for the use and acceptability of the system and its respective products. This also means that the network and community that employs the system can be disadvantaged due to such discontinuation. **Respondent D** highlighted that strengthening of IPPs can contribute to lowering the rate of diffusion of innovations in a specific sector while also reducing the rate of adoption by other stakeholders. Although this may be good for strengthening market exclusivity of the product for the innovator, on the other hand it can constrain the uptake of the product and system in the mainstream market especially in situations where the innovator is no longer keen to continue availing the product.

5.4 Data Overview for Sub-Question 4: Addressing Perceptions and Barriers through Incentives and Institutional Support

This section addresses the fourth sub-question which focuses on identifying and discussing avenues of strengthening incentives and institutional support to respond to some of the existing perceptions and barriers to the diffusion of interlocking blocks.

Table 15: Data overview for sub-question 4 data overview: Incentives and Institutional Support.

	Are there any incentives (internal or external) for using low carbon building for encouraging the use of diverse low carbon materials and technology?	Do you think efforts towards using innovative building technology are adequately supported?	How do you think green building materials can be better supported?	Where do you currently get ongoing support with the use of green building materials
Respondent A	○ Partly. There is very limited local support for alternative building ○ Support in SA focuses on socioeconomic issues: lack of affordable housing, uplifting women in construction, youth employment and waste management, training and empowerment. Hustlenomics received support from the following entities: ○ SAB offered us financing and mentorship support, equipment if and when required ○ Y-GAP has supported us through intensive workshop sessions for a week which were targeted at unpacking our 'why' and made available a R10 000.00 grant fund upon application and invoicing ○ SEED- international award for green innovation ○ Coins- seek to support innovation in construction from which we received R50 000.00 for winning second place in a competition ○ GEP (Gauteng Enterprise Propeller) – we entered a competition and won R 75 000.00 ○ Chivas – we won in SA and we were then supposed to represent SA in the USA ○ - Red Bull Amaphiko – non-financial support that helps you learn how to pitch and structure our thoughts. After our feedback they even partnered us with SAB	No. Local support programs are typically a tick box exercise for record keeping: ○ Practice of corruption: Our experience with GEP, Kasi Entrepreneurs. ○ The unfortunate thing is that not all small businesses have the luxury to reject the additional informal T&Cs that come with the support in this country, they cave from a position of desperation		Hydraform is a South African manufacturing company that has been around for years. The advantage with sourcing from a local machinery supplier is the additional support required to operate these machineries adequately. The benefits of using Hydraform is that if it breaks down or you need an additional part of the machine or an accessory, you can just contact Hydraform and get a better turnaround time as opposed to looking for an overseas supplier and not knowing when you'd actually receive the ordered parts.
Respondent B	○ Hydraform used to have something similar to a training Academy prior to the COVID-19 pandemic, which was conducted once or twice a year		Better education on the use of ABMS	○ We give on-site support for Maintenance ○ We have started with webinars as well as

	○ As a machinery supplying company, there is no specific support for the work we do. We just get recognition and certification like any other company for a specific product ○ We are accredited by NHBRC and Agrément We've been accredited as an approved constructor and supplier			online stations where we do training ○ The sales department has a turnaround time of about 48 hours for all year round
Respondent C	We do not have any incentives within the organisation		○ More appetite by City for alternative energy and products ○ Use the opportunity in tender prescriptionsIncentivize creative thinking	
Respondent D	No, there aren't grants or incentives so far		I think there needs to be an investment injection. Because you have all these technologies, not like they are not there, we have them. They've been shelved because nobody is putting them into action. Nobody is buying into that technology Yeah, the people demand that technology, but before the people can acquire that technology, don't want to be trained or prepared for the technology South Africa wants to do things for themselves, this is exemplified by the proliferation of informal settlements. This tells you that people want to do things for themselves and it is evident from the way these makeshift structures are put together. You go to rural areas there's hunger for new things or doing things differently, but there's just no support You know if interlocking blocks were available at local hardware stores, there is a chance that people would consider them as an alternative to conventional building material	Not necessarily, we are regulators
Respondent E	No.	Insufficient	○ Government made an announcement that all government funded projects need to use only local cement. So, we're not supposed to be outsourcing cement from other countries ○ Maybe a project needs to comply 20% for the current green building standards. Then I think that would be the first step towards green building ○ Green star ratings should be a requirement. Then a lot of construction projects would be forced to comply with the architects and their specified products	

Respondent F	Not really. The only support worth mentioning are the voluntary seminars, conferences and workshops held through the South African Institute of Architects (SAIA). We pay a fee to participate. So, the growth and knowledge expansion, even though it is to the benefit of the society, is paid for by those who attend. The onus is left to the person who's already studied, equipped themselves, and now there's a new layer that they need to be considering for the greater good, and not necessarily all they could, to some extent.	Not at all	Real access: the green materials I've seen are either ordered from overseas or there's enormous waiting periods before they are delivered or ready for construction Disparity between what the architect's design specs vs what the contractor can get Logistics: dead material wasn't coming fast enough A living document, that exhibits tested alternatives buildings. You know 40 years is the minimum that material is supposed to give you when it's the exterior skin of the structure For additional educational programs to be for free and fully funded by the state	○ Bearing costs for further training. ○ Bearing the risk ○ Strong social resistance to change
(Secondary Sources		Increase government projects and models to align to NHBRC requirements and relevant Agrément certification (NHBRC, 2020)	More effort is required to educate the public about Innovative Building Technologies. These need to be tied to the local community in order to facilitate local economic development and yield better success (NHBRC, 2020) for: Value for Money: The system should cut costs through materials and labor whilst ensuring that reliability of the structure is retained Technical Performance: The system should consider critical elements of energy efficiency, acoustics, durability and fire protection Contractor Friendly: It should be easy to transfer the technology. Technology owners should be able to easily train local people as part of local economic development and capacitation According to Mpakati-Gama *et al* (2012), referring to an Ethiopian Case Study, governments have the power to influence the change in product or material use through setting standards, guides and regulations	Built environment professionals actively working under LETI towards a zero-carbon future for London believe that setting the target at 10% for all new development to meet the requirements of the Climate Emergency Design Guide would assist in meeting the set climate change targets (LETI, 2021)
	Sub- Findings: ○ Noted a need for building more awareness of IBTs to inform not only professionals but clients and end-users as well ○ Noted a need for stronger accountability systems to curb corruption and incompetence that negatively affect the limited support that exists is required ○ There is little to no support for utilizing low carbon building materials and incentives for developing low carbon sustainable settlements. This suggests that there is a need for more incentives to foster the paradigm shift towards the adopted green agenda policies ○ Respondents suggested a range of tools and strategies that could be utilized to help advance the building material sector in the desired direction ○ Improvement and flexibility within the existing supply chain management, particularly in the public sector required			

5.5 Tackling Inadequate Support: Institutional, Market, Financial and Supply Chain Management

Data overview from Table 1 indicates a general consensus that incentives for organisations, professionals and end-users to look into energy efficient approaches and products are extremely limited. All respondents consistently expressed that there are inadequate tools and instruments that encourage actors to explore options and IBTs outside their status quo and familiar methods of construction. The respondents affirm that there is a need to focus on the following critical areas to improve the adoption of interlocking blocks and other related ABMS. Key among the suggested interventions are:

- More focus on social impact (grants/ competitions)
- Corruption in Local Organisations
- The Role of Supply Chain Management
- Regulatory Frameworks and Standards
- Creating Political and Social Will

5.5.1 More focus on social impact (grants/ competitions)

Respondent A is of the opinion that there is very limited support for alternative building modules or methods in South Africa compared to attention from international organisations. The support Hustlenomics typically received is based on the social issues that the business responds to as opposed to the environmental benefits associated with interlocking blocks. Hustlenomics is usually supported for being social entrepreneurs that respond to socioeconomic challenges which include lack of affordable housing, uplifting women in construction, waste management, youth employment, training and empowerment.

R**espondent A** has received support from recognized institutions and that is how they have managed to unlock more financial support as a result of improved credibility and trust with funders and investors. This has also contributed to the expansion of their online footprint. As a way to stimulate enthusiasm towards ABMS within the construction industry, key role players need to create ways of making grants available and also facilitate competitions among innovators while also encouraging other forms of incentivising both supply and demand side of the market.

5.5.2 Corruption in Local Organisations

There is a real need for more authentic local support for alternative building materials and approaches. As mentioned in Table 11, **Respondent A and C** lamented that for many local programs this is treated merely as a tick box exercise. **Respondent A** added that their organisation has experienced corrupt conduct which reflected that some local programs had very little concern for struggling small businesses. For instance:

- **Respondent A** narrated their experience with South African Institute of Chartered Accountants (SAICA) - an accountancy body in South Africa. They participated in some of the workshop sessions that were set up to help small businesses with getting an accounting system in place. Unfortunately, they did not get the expected level of assistance. However, a year later, the organisation wanted **Respondent A** to provide feedback on the workshop session and the 'assistance' received and they refused. Under normal circumstances and as with any other professional body, this would be regarded as unethical business practice
- After winning a competition, the organisation wanted to regulate how and where **Respondent A** would spend the winnings. He further stated that "I needed to buy from companies that are registered with the Central Supplier Database (CSD), and my trouble is that I needed an additional machine from a company that doesn't need to be registered with the CSD so they couldn't pay. They proposed that they have a person with a company that has a CSD and they would pay into that third-party company at an additional 25% for them to buy on my behalf. I refused and I told them to keep the money as I would not just give someone 25% of my R100 000 winnings for doing something I could've done myself." As **Respondent A** recalls – "after a year, they reached out to follow up on my claim to see if I was now desperate enough to follow the newly established untoward Terms & Conditions and I still refused to cooperate"
- Kasi Entrepreneurs hosted a competition for which the prize money was R40 000. Upon winning they dictate how one should spend the money and where to seek support which appeared to be a redirection of the funds back into the representatives of the organisation. These are a few of many other corrupt activities that small businesses are subjected to when trying to access financial or institutional support from local organisations.

5.5.3 The Role of Supply Chain Management

As highlighted in Monczka *et al* (2016), supply chain management plays a key role in product development, sourcing, and logistics. By virtue of its scope it has the potential to influence attractiveness, demand and utilisation of ABMS. Evidently, the supply chain management in place has not positively influenced the use of interlocking blocks and other ABMS. As a result, conventional methods and materials are perpetuated thus escalating the degradation of the natural environment. According to **Respondent C**, the procurement systems in place need to be enablers for the diffusion of ABMS. The Johannesburg Property Company (JPC) as well as other state departments can encourage the development, sourcing and use of ABMS through their supply chain processes. As detailed in the previous chapter, supply chain has a critical role to play in fostering ABMS strategies in order to promote change from outdated conventional methods and systems that are detrimental to the environment.

With reference to the National Treasury's October 2021 decision to ban the use of imported cement on all government-funded projects from the 4th of November 2021, **Respondent E** argues for similar intentional actions towards the prioritisation of low carbon development and building materials. Similar directives are necessary in the supply chain of low embodied energy building materials. According to Cokayne (2021) from Moneyweb, the decision by Treasury was meant to protect local cement producers and manufacturers from cheaper imports in order to ensure increased growth in the local economy, job creation and business sustainability. The ruling had positive results in the share price of local JSE listed cement and building material producers as demonstrated in subsequent increase their share prices (see Figure 16).

Figure 16: Reflection of the increased share prices for PPC and Sephaku during 2021 (Source: Cokayne, 2021:1)

5.5.4 Regulatory Frameworks and Standards

The uptake of AMBS should be incentivized through sound government policies, strategies and frameworks. For example, upon the realisation that the manner in which affordable housing was provided is unsustainable and had unintended consequences such as the fragmented spatial environment it perpetuated, government developed the Breaking New Ground (BNG) policy in 2004. This policy sets good precedents as it aimed to change role of the then Department of Housing from merely providing houses to enabling the development of sustainable human settlements (SACN, 2014). This shift in itself should have been

perceived as an opportunity to introduce ABMS to support the move towards sustainable practices.

Referring to an Ethiopian Case Study, Mpakati-Gama *et al* (2012) notes that governments have the power to influence change in product or material use through setting standards, guides and regulations. For instance, the ban of endangered wood species in the 1990s in Ethiopia led to the scarcity of certain wood types and as a consequence the building sector resorted to alternative wood, which unfortunately did not possess the same quality as the banned wood species. The same approach can be adopted for the South African context, even though the regulation would not necessitate the banning of any material but could instead create a quota system which would require developers to dedicate a certain percentage or portion of their work to green building. Over and above this, there should be a standardized and consistent system of measuring the performance of buildings based on embodied energy consumed from the extraction of raw materials up to the use and eventual demolition of the structure.

As emphasised by **Respondent C and E** there is a need to update conventional policies to include strategies that will encourage developers to shift from the use of conventional and traditional materials towards low-carbon materials. **Respondent E** notes that the first logical step would be to enact a policy for mandatory requirement on projects to comply to a minimum of 20% with the current green building standards and set sustainability targets to be achieved. A group of over 1 000 built environment professionals actively working under LETI towards a zero-carbon future for London believe that setting the target at 10% for all new developments to meet the requirements of the Climate Emergency Design Guide would assist in meeting the set climate change targets (LETI, 2021).

5.5.5 Creating Political and Social Will

- Increase awareness of Alternative Building Materials and Systems (ABMS)

Educating the general public or clientele about the importance of innovative building technologies (IBT) or Alternative Building Materials and Systems (ABMS) and associated environmental gains would instil knowledge and influence perspectives. This would ultimately lead to increased demand for related products (interlocking blocks in the case of this research) within a reasonable time period.

- Emphasis on benefits of ABMS

South African National Building Regulations more often than not focus on “what the required level of performance of a building or material is, rather than stipulating how this level is to be

achieved" thus leaving room for freedom of choice and flexibility (De Villiers and Boshoff, 2012: 4). Choices on how the required level of performance is to be achieved often rests with the professional judgement of the experts (architect, engineer, landscape architect, quantity surveyor etc.). Technical experts are therefore uniquely positioned to influence material selection towards achieving the required outcomes based on further guidance under the South African Bureau of Standards (SABS) who regulate compliance to standards by materials manufacturers.

- Obtaining Innovative Building Technology Finance and Support

The availability of financial and non-financial support for the promotion of alternative building materials and systems (ABMS) has a direct impact on their rate of diffusion. De Villiers and Boshoff (2012) consider conducive economic and market conditions, investor confidence and financial resources as key variables that can improve the diffusion of interlocking blocks as well as other form of ABMS in the market. As alluded to by all of respondents, the market currently favours conventional methods of housing development and construction, with hardly any incentives or different forms of financial support to enhance adoption of sustainable building materials. **Respondent A** further states that local support for alternative building modules or methods in South Africa remains extremely low in spite of their energy efficiency as well as increasing attention from international organisations. In a similar note, Mpakati-Gama *et al* (2012) used the example of market reforms and review of regulatory frameworks in Tanzania and Kenya to show how these can contribute to the diffusion of interlocking blocks. In particular, their study made reference to subsidies granted to developers for the purchase of ABMS in order to encourage them to use such alternatives as opposed to conventional materials.

Respondent D consistently raised the need for more investments directed towards supporting the developed and upcoming building technologies and systems archived in the NHBRC's IBT database. The respondent argued that South Africa, and the CoJ more specifically, finds itself in an advantageous position where a significant part of the IBT research and development already exists. However, adequate long-term support to advance the IBTs is limited and thus inhibiting their acceptability and availability in the market.

- Improved Visibility and Access

Some of the respondents have highlighted that facilities that offer readily available ABMS in the market are not easily accessible. **Respondent A** for example notes that local hardware stores such as Cashbuild, Builders Warehouse and Build-It are about making shelve-room for products that are already known, wanted and marketed as well as easy to use. As a response

to this challenge, one of the critical steps would be to make ABMS easily accessible and widely available as an alternative in the interest of environmental sustainability and other secondary benefits. This can be through new hardware stores or retrofitted sustainability focused units within existing hardware stores. Beyond being present in the form of physical infrastructure such stores should actively promote innovation in construction materials as part of promoting an overall culture of sustainable resource use.

- Knowledge Sharing and Expertise

Mpakati-Gama *et al* (2012) notes that expertise plays a critical role in ensuring successful implementation of ABMs in construction mainly because when such expertise is engaged, it enhances the quality of resultant building stock. **Respondent A** attributes his successful utilisation of interlocking blocks to exposure he gained from travelling to other countries through competitions and seeing how progressively such countries are pursuing environmentally friendly construction.

Respondent D also asserted that while informal settlements are reflective of scale to which people are living in poverty, they also reflect the South African culture of self-help and eagerness to learn and act even where resources are limited. Informal settlements thus constitute a prime example of people building in an efficient manner through the reuse of existing building materials commonly salvaged from demolition waste. However, there is reluctance in educating and empowering such actors in marginalised communities about IBTs possibly because of related higher costs compared to salvaged materials and possibly their unwillingness to identify with the championed environmental benefits.

5.6 Sub-findings to the Sub-Question

Difficulties noted under barriers and perceptions are closely interconnected and mainly relate to inadequate policy and regulatory support, costing and lack of responsive institutional structures. The sub-findings also highlight that considering the use of ABMS requires building strong awareness and basic knowledge of ABMS to develop community acceptance prior to the commencement of responsive projects and related construction. Taking advantage of the growing market and the economic opportunities requires a community's willingness to learn about the use and benefits of ABMS. However, as in the example of earth construction reviewed in Mpakati-Gama *et al* (2012), it is usually promoted in developed countries because of its green attributes such as low embodied energy but systematically avoided among low-income communities due its poor aesthetics, unreliable structural strength against earthquakes and low durability, especially where the required expertise is not readily available or affordable.

CHAPTER 6: CONSOLIDATION OF OVERALL FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

6.1 Overview

The study was motivated by the expectation that increased uptake of energy efficient building materials and their respective construction processes would significantly contribute towards the provision of low carbon housing. The aim of the study was therefore to identify and assess market related opportunities and challenges confronting the uptake of low embodied energy building materials with particular focus on interlocking blocks in the context of Johannesburg. The secondary objective was to also identify forces that influence the current levels of diffusion of low carbon building materials and other Green Building Materials (GBMs) within the mainstream market based on engagement with built environment professionals. In doing so, the study developed four sub-questions in order to derive detailed sub-findings at a much deeper level. Insights from responses of the sampled respondents as well as secondary data sources informed the sub-findings in relation to each of the sub-questions as derived in Chapters 4 and 5. In this chapter, the sub-findings were consolidated into overall findings followed by conclusions and recommendations of the study.

6.2 Consolidation of Overall Findings

Table 16: Sub-findings and overall findings

Sub-Question 1: **What are the critical perceptions on interlocking blocks in the Johannesburg housing construction market?**	Sub-Question 2: **How do interlocking blocks contribute to the agenda for reducing low embodied energy in construction building materials compared to conventional bricks?**	Sub-Question 3: **What are the key barriers to the diffusion of interlocking blocks in the residential development sub-sector of the construction industry?**	Sub-question 4: **How can the perceptions and barriers be addressed to enhance the uptake of innovative sustainable building materials?**
○ Sub-finding 1: General perceptions informed by existing knowledge, exposure and limited acceptance of the products. Project value chain roles also influenced perception of ABMS and consideration of interlocking blocks. The study notes clear levels of awareness and interest among respondents, but unwillingness to engage with implementation challenges ○ Sub-finding 2: Cost, durability and speed as the three prioritised factors	○ Sub-finding 1: the significance of using interlocking blocks was found to be related to production processes as well as dry stacking building method. The differences noted on experience with IBT and other ABMS included: aesthetic quality, cost reduction and time saving in construction stage ○ Sub- finding 2: A niche-market developer, whose work focuses on the backyarding phenomenon, demonstrated that alternative building products are affordable and are of good quality. ○ Sub-finding 3: The concept of cost criteria in the construction sector is	○ Sub-finding 1: Noted poor accessibility of IBTs in the mainstream market avenues as one of the most pressing concerns. The inaccessibility of IBT was related to poor or negative public perception ○ Sub-finding 2: The mix-match between policy and practice, for example, City of Johannesburg has a range of strategies and policies that reflect commitment to the agenda for climate change action, while procurement and tender processes do not reflect strong intent nor do they incentivise the use of IBT in line	○ Sub-finding 1: Alongside promoting awareness of IBTs, stronger emphasis on disseminating their social impact and benefits is required. This is critical for evolving full appreciation of IBT benefits especially for interlocking blocks ○ Sub-finding 2: Critical need for strategies to enhance accountability by curbing corruption and incompetence that negatively undermine the limited support that exists ○ Sub-finding 3: Improvement and flexibility within existing

when it comes to selection of building materials. Based on the three factors Interlocking blocks and other ABMS perform better than conventional building materials ○ Sub-finding 3: On views on interlocking blocks, most respondents are aware of ABMS/IBTs but have very limited knowledge on interlocking blocks. By virtue of the very limited awareness of interlocking blocks, there are no clear perceptions on interlocking blocks specifically ○ Sub-finding 4: The lack of awareness was attributed to poor marketing strategies, inadequate readiness by government and poor public knowledge around ABMS and more	only understood in terms of immediate financial and time factors and therefore disregards other long-term implications which can arguably be considered to be environmentally taxing. These include environmental health and embodied energy/carbon impacts ○ Sub-finding 4: Noted clear institutional support with regards to quality assurance through certification for IBTs. However, the expensive renewal of certifications also acts as an additional barrier for product developers ○ Sub-finding 5: Opportunities for recycle of post construction waste and ease of construction allowing engagement of women and less skilled youth was clearly demonstrated	with the existing commitments towards net zero agenda of CoJ. ○ Sub-finding 3: Curriculum within higher education sector does not adequately cover the importance of selecting more appropriate building materials and their related benefits. Nor does it build confidence for professionals to take the necessary risks involved with utilising IBTs like interlocking blocks ○ Sub-finding 4: On regulatory requirements and processes, both technical and political considerations influence decision-making process of respondents ○ Sub-finding 5: Lack of meaningful support of the IBT and ABM niche market,	supply chain management, particularly in the public sector critical in effectively directing and encouraging more inclusive building material selection processes

specifically interlocking blocks		particularly in reference to actors breaking new ground and introducing new strategies in the built environment. There is need for more incentives to foster transition towards adopted green policies that set out sustainable developmental principles and goals. Absence of necessary instruments like incentives is counterproductive to national, provincial and city-wide commitments to reduce GHG-emissions	
Overall Findings in response to overall research question (How could the diffusion of interlocking masonry blocks be accelerated towards facilitating the provision of low-carbon sustainable human settlements in Johannesburg?)	○ **Finding 1:** Local government has the potential to be the centre for driving change and acceptability of innovative products as a significant portion of the City's annual budget is allocated to the provision of a range of housing stock. Another key shortcoming of policy-makers is the oversight made on equipping key implementers and public officials with the right translation of policies and commitments on the ground. Beyond declaring commitments through adopting policies, local government needs to translate the understanding and targets to actionable Key Performance Indicators (KPIs) for the relevant departments and Municipal Owned Entities (MOEs). In addition to minimising the gap between policy and practice, public-sector stakeholders need to encourage the use of IBTs by promoting awareness in communities through workshop sessions, education programs and skills development initiatives ○ **Finding 2:** Existing organisations that drive the environmental efficiency agenda in construction and built environment need to aid in building stronger linkages for businesses and end-users in terms of choices and patterns in GHG emissions reduction. Currently relationship between consumption and long-term environmental impact is supposedly viewed to be far-fetched. All actors within the value chain of any built project need to better understand how their		

	selection of building materials has direct and indirect impacts on the state of the environment and resource consumption. Not only can this develop better patterns but can also develop a stronger sense of accountability. Organisations and relevant bodies need to relook at certification avenues to ensure that they do not further restrict the growth of IBTs, particularly for start-up businesses breaking ground and aiming for growth ○ **Finding 3:** Cost benefits of interlocking blocks can only be derived on the basis of a project in its entirety. The way in which project costs are understood and calculated needs to be revised to include long term outcomes as well. Continued use of this limited and distorted view of bottom-line financial costs of projects, conventional building materials will remain cheaper and more viable compared to the use of ABMS in the South African context as their environmental and socio-economic costs remain hidden ○ **Finding 4:** The study therefore established a need for building stronger linkages and trust for ordinary stakeholders to see the impact of building materials on the overall agenda for lower GHG emissions and decarbonising as well as their contribution through more responsive choices of building materials. This has the potential to subsequently increase the level of awareness and adoption ○ **Finding 5:** The inability to achieve both just and sustainable outcomes is not necessarily reflective of a lack of willingness, but rather the lack of explicit strategies (actionable tasks) to foster these imperatives especially in view of the complex set of factors and trade-offs involved across the decision-making processes ○ **Finding 6:** The typical practice is that system providers introduce a specific material, get the necessary certification and build a targeted project. Thereafter the system is shelved and the rights to produce a specific IBT remains exclusive. This acts as a drawback to long-term availability of IBT in the market. Addressing the monopolistic nature and gatekeeping propensities of businesses within the low carbon building material market would render ABMS and IBTs more accessible and also improve stakeholder awareness and acceptability

	○ **Finding 7:** With increased accessibility, the study highlighted a significant gap in the current environmentally conscious offerings within existing mainstream builder's stores and warehouses. This gap is an area of opportunity for the IBT product offering like interlocking blocks. Aligned with the assertions from professional respondents, the market needs to make shelf room for these products for ease of sourcing by designers and builders.
Overall conclusion relative to objective and motivation for the study	It is through the above findings that the research has formulated response to the argument that indeed the adoption of ABMS/IBT can be accelerated and by so doing, reduce GHG-emissions in the housing construction in Johannesburg provided that: ○ **Conclusion issue 1**: ABMS become easily accessible and widely available especially through providing sufficient shelve room in local hardware stores such as Cashbuild, Builders Warehouse and Build-It. This can either be through new hardware stores or retrofitted sustainability focused units within above mentioned hardware stores ○ **Conclusion issue 2**: There is increased support for ABMS in South Africa through programmes and grants that would respond not only to social ills but also socio-environmental challenges. The outcome of the additional support would eventually lead to the growth of small businesses such as Hustlenomics venturing into the green building economy ○ **Conclusion issue 3:** there is sufficient institutional support for professionals and business with keen interest in ABMS/IBT, by way of reducing corruption within local organisations and institutions that are entrusted with the safe keep and growth of small business driving innovation within the construction sector. Furthermore, more synergies and collaborative efforts between public and private entities in providing institutional support for SMMEs breaking ground within the IBT housing market to ensure the provision of adequate financial and non-financial support. ○ **Conclusion issue 4:** There is a need for change in the existing public sector procurement systems to encourage the development, sourcing and use of ABMS through their supply chain processes. With reference to the formulation of Requests For Quotes (RFQs) and Request For Proposals (RFPs), promoting sustainability should not only be limited towards optimising energy efficiency in buildings with the focus on electricity and water concerns, but should also

	include ABMS/IBT. The green building component of sustainability in such RFQs should be more direct and specific, while also stressing the importance of going beyond the usual considerations to create truly low carbon housing with real impact. o **Conclusion issue 5:** Standards, guidelines and regulations are formulated to influence change in product or material use. Unlike other African countries (as noted in Section 5.5.4) this does not imply the banning of any material but could instead entail a quota system which would require developers to dedicate a certain percentage or portion of their work to green building o **Conclusion issue 6:** There is effort to instil knowledge and influence perspectives through educating the general public or clientele about the importance of ABMS/IBT and associated environmental gains. In addition to regulatory bodies benchmarking the required performance standards of building materials, they also need to stipulate how the prescribed levels need to be achieved. o In the absence of the above, the adoption of ABMS/IBT will not be accelerated and as a consequence, low carbon housing will not be considered as a critical component of sustainable human settlement development. This in turn would perpetuate the escalating GHG emissions associated with housing development due to increasing rate of urbanisation
Limitations (how effectively data and method explain what the study aimed to explain versus what still remains unexplained) and Recommendations for further studies in particular	o **Limitation issue 1:** There are limited interlocking blocks companies in Johannesburg. This means that there is only a few interlocking block companies to engage and form part of the sample group of respondents working in Johannesburg. This also means that the research had to focus on the experience of Hustlenomics and Hydraform. While this enables for an in-depth observation of the workings of Hustlenomics as the primary interlocking blocks developer, it also meant that experience would only reflect the process adopted with their target group being homeowners seeking to redevelop backyard housing from shacks

	○ **Limitation issue 2:** Another limitation to note, is the small sample size of the respondents used in the fieldwork. While purposive respondent sampling was an intentional strategy in selecting the appropriate group of respondents (as reflected in Section 3.3.4), the small sample size constitutes a shortcoming of the study since it only takes into consideration the perception and experience of only a few built environment professionals and other actors/stakeholders in the large construction sector. This suggests that the views gathered may not fully be representative of professionals within the built environment sector. Subsequently, readers need to approach the current findings and conclusions with caution as the current interpretations of the outcomes are limited to the sampled group interviewed for the research ○ **Limitation issue 3:** In the South African context, specifically Johannesburg, research on the use of interlocking blocks is wanting. This includes lived experiences of people living in homes that are built using interlocking blocks. This posed shortcomings to the findings of the research as the researcher did not solicit views and experiences of end-users as they refused to participate in the research. While the researcher had initially intended to incorporate the perceptions held by end-users of ABMS/IBT, the researcher did not get consent and as a result their views were not taken into account within data presentation and analyses

6.3 Overall Findings and Conclusions

As mentioned in Section 1.8, the determination of the study is that the gap in the uptake of interlocking blocks and other IBTs is related to unfulfilled market opportunities in the green economy and related barriers that need to be tacked. The working hypothesis of the study is that an increased uptake may be seen when market-oriented initiatives aimed at increasing the awareness of the benefits associated with the use of green building materials are supported. Market- oriented initiatives also need to lessen the existing obstacles that limit the uptake and overall growth of innovative low carbon construction strategies. The research has identified market opportunities that need to be leveraged as well as the ways in which the obstacles can be addressed.

6.3.1 Market Opportunities and How to Leverage Them

- Potential contribution to GHG-emission reduction towards net-zero goals

Given that an estimated 39% of the overall global carbon emissions emanates from buildings, decarbonising the built environment sector needs to be prioritised as a key strategy towards mitigating climate change. The study has demonstrated how the use of IBTs can contribute to the realisation of low carbon housing development and thus lower GHG emission in the sub-sector. To leverage on this identified opportunity bottlenecks/ barriers identified in this study should be systematically addressed.

- Systematic quality assurance in place

Quality management is an important part of ensuring safety, performance and consistency in product development. Existence of systematic quality assurance regulators was identified as crucial for fostering innovation within the IBT market. However, the systems currently in place still need to be leveraged to drive innovation rather than blocking it. Regulators and organisations that advocate for the use of IBTs need to continue developing systems to respond to new ways of doing business.

- Reuse of Post Construction Waste

To adequately leverage the identified market opportunity that exists in the reuse of post construction waste, a range of efforts can be adopted centred around information sharing, building better understanding on recyclable waste, developing technical specifications and policies such as sustainable procurement and stimulating the market through tax incentives. From the state end, municipal organs like Pikitup in the Johannesburg context need to drive efforts towards better education of businesses and recyclers on the choices of recycled

products. The municipality could also institute specific post construction waste sites in the transformative areas with the most intense construction activities within the City to encourage both contractor and recycler involvement. Socio-environmental organisations also have a role to play in improving the knowledge about post construction waste reuse in construction materials and products among communities and professionals. The use of tax break to influence the cost/affordability of the products also has the potential to further encourage more players into this specific market.

6.4 Barriers and How to Address Them

- Perceptions

The negative perceptions and attitudes held towards ABMS/IBT were found to be closely linked to cultural and social resistance as well as poor client knowledge on ABMS/IBT. To encourage sustainable buying patterns and building material selection choices, the City could roll out programs, campaigns and open days for products to be better marketed, as well as utilise social media platforms to make the use of ABMS trendier. In addition to the outreach programmes, the use of pilot projects of the use of interlocking blocks would also benefit communities in building familiarity with the technology and also provide physical demonstration. Higher institutions of learning should also participate in the bid to change perceptions, through ensuring that the undergraduate and postgraduate curriculum explicitly includes fundamental information and accurate data on ABMS. There is also a need to establish incentives to drive the take-up of sustainable design practices.

- Ineffective policies with minimal incentives and inadequate support at implementation level

For climate change action policies to be effective, goals need to be translated into Key Performance Indicators (KPIs) and implementable actions for the relevant departments and Municipal Owned Entities (MOEs). This can be achieved through annual allocation of budget that would be dedicated to the green housing stock. In addition, policy is more effective when communicated through workshop sessions, education programs and skills development initiatives. Through these platforms, the knowledge shared can be translated into actions by the general public.

- Narrow-sense of costs

The research has demonstrated that the continued linear application of cost does not take into account other critical factors which are important to realising sustainable settlements. To

adequately address this obstacle, built environment professionals need to adopt holistic costs approach which favours ABMS/IBTs. The construction sector needs to move towards the use of holistic sustainability evaluations for construction measures. Indirect effects like the level of embodied energy play an important role in the sustainability assessment of development and this needs to be better incorporated into overall performance. More emphasis needs to be applied to the interrelation that exists between direct and indirect costs implications of projects. The integration if holistic cost approaches can in turn address the current applied approach to construction costs.

6.5 Recommendations for Further Research

Insights from interview responses have highlighted various avenues to pursue further investigations. This section articulates recommendations based on sub-findings in chapters 4 and 5. The recommendations for further research include:

- Critical participants, end users of interlocking block houses did not wish to participate in the study as interview participants. Most of the data related to the views and considerations of homeowners were collected through secondary data collection in the form of reports and articles. For a nuanced and clarified understanding from the beneficiaries' perspectives, the study recommends that a follow up study be conducted. Such a study would help in highlighting any other details and perceptions held by users of resultant housing as some of the critical actors and stakeholders

- As highlighted in the overall findings, policymakers must adopt an integrated approach in order to ensure successful implementation of climate change mitigation through energy efficiency policies in housing. The study concludes that supportive instruments and policy with concomitant regulations are imperative to the exploration of uncharted market opportunities while addressing the barriers to the diffusion of interlocking blocks and other IBTs. The study therefore advocates for more research to be conducted in the area of developing a clear pathway to policy implementers to execute the visions in order to adequately meet the committed targets towards net-zero developments in Johannesburg

- As highlighted in the conclusions, the experience of interlocking blocks may vary based on the climatic conditions in different regions of South Africa. This suggests that it may be favourable in moderate climate regions such as

Johannesburg. Given this, the research recommends a follow up study to be conducted to investigate and contrast the experience of interlocking blocks in other regions of the country. Further studies may reveal the appropriate conditions and perhaps the strategies of adopting the use of interlocking blocks per region in South Africa

- As stated in Section 6.3, the reuse of post construction waste presents an opportunity to accelerate the adoption of net-zero residential developments. This study therefore recommends that more research be conducted further research towards adequately investigating the use of post construction waste in the production of interlocking blocks and other ABMS/IBTs

- Narrow sense of costs prevalent in most projects favour conventional materials and methods as it disregards holistic costs which are likely to be in favour of ABMS/IBTs. Further studies could also focus on formulating a standardised and comprehensive calculation system which would assist in factoring holistic costs accurately to incorporate not only direct monetary cost implications but also indirect costs associated with embodied energy across project development stages from cradle to grave and related contribution to GHG emissions

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APPENDICES

Appendix 1 – Interview Guide Questions

Revised Research Questions

Sub Question 1: What are the critical perceptions on interlocking bricks in the Johannesburg housing construction market?

Core Concept: To identify the views and analyse the context related rationale

Interview Questions:

1. What factors influence the choice of building materials for your projects/ organisation/ store?
2. How would you grade your level of awareness of green building materials? (low/ moderate/ expert)
3. What are your thoughts on green building materials?
4. How would you grade your level of adoption innovative building materials? (low/ moderate/ high)
5. Have you ever considered innovative building technology or building materials for your projects/ organisation/ store?
   If Yes, which ones?
6. Have you ever heard of interlocking bricks?
7. If yes, where did you first hear of it?
8. If so, what were your initial assumptions of it?

Sub Question 2: How do interlocking bricks contribute to the agenda for reducing low embodied energy in construction building materials compared to conventional bricks?

Core Concept: To understand the material difference and value add of interlocking bricks

1. Does this organisation support low carbon development and building materials? If so, how?
2. To what extent does this organisation prioritise low carbon development?
3. What is the difference between interlocking bricks vs the conventional bricks?
4. Are there any environmentally or energy related benefits noted with the use of interlocking bricks?

Sub Question 3: What are the key barriers to the diffusion of interlocking bricks in the residential development sub-sector of the construction industry?

Core Concept: To identify the hindrances and recommend strategies for barrier reduction

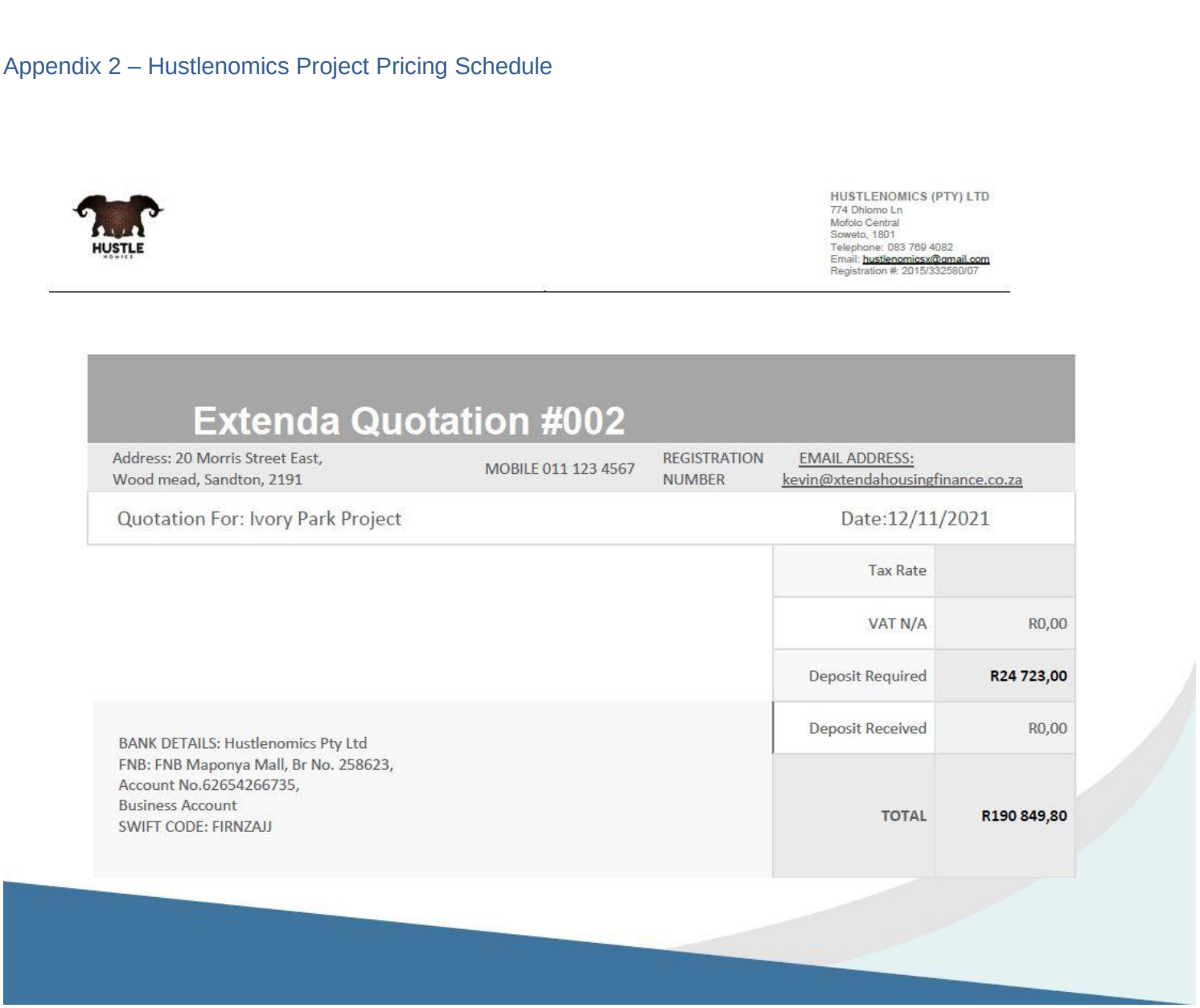
1. What challenges does this organisation/ company face with regards to prescribing low carbon construction materials with a low carbon footprint?
2. How accessible are interlocking bricks and other innovative building materials? (poor, moderate, high)
3. Are there any challenges to their accessibility to in the mainstream market? If so what are they?
4. What are some of the challenges professionals face with regards to designing, specifying and managing the use of green building materials?

Sub Question 4: How can the perceptions and barriers be addressed to enhance the uptake of innovative sustainable building materials be further supported?

Core Concept: To reflect on the existing or lack thereof the instruments that can aid in the uptake enhancement

1. Are there any policies/ programs/ grants/ plans for encouraging the use of diverse low carbon material and technology in your organisation/ company?
2. Are there any incentives (internal or external) for using low carbon building in your organisation/ company?
3. Do you think efforts towards using innovative building technology are adequately supported and encouraged to both industry experts and end-users?
4. **H**ow do you think some of the identified challenges your business faces with regard to the use of ABMS can be addressed?
5. How do you think green building materials can be better supported?
6. Where do you currently get ongoing support with the use of green building materials

Appendix 2 – Hustlenomics Project Pricing Schedule



HUSTLENOMICS (PTY) LTD
774 Dhlomo Ln
Mofolo Central
Soweto, 1801
Telephone: 083 769 4082
Email: hustlenomicsx@gmail.com
Registration #: 2015/332580/07

Extenda Quotation #002

Address: 20 Morris Street East, Wood mead, Sandton, 2191	MOBILE 011 123 4567	REGISTRATION NUMBER	EMAIL ADDRESS: kevin@xtendahousingfinance.co.za

Quotation For: Ivory Park Project — Date:12/11/2021

Tax Rate	
VAT N/A	R0,00
Deposit Required	**R24 723,00**
Deposit Received	R0,00
TOTAL	**R190 849,80**

BANK DETAILS: Hustlenomics Pty Ltd
FNB: FNB Maponya Mall, Br No. 258623,
Account No.62654266735,
Business Account
SWIFT CODE: FIRNZAJJ

Description	Item #	Unit Price	Price
WEEK 1			
foundation trenching & pouring			
140mm x Maxi bricks	1500	R5,00	R7 500,00
CONCRETE MIX YD P/M3	12	R385,00	R4 620,00
Building Sand	6	R260,00	R1 560,00
SUREBUILD CEMENT 42.5 SOKG YARD	88	R96,00	R8 448,00
River sand	3	R385,00	R1 155,00
Transport	2	R720,00	R1 440,00
			R24 723,00
WEEK 2			
foundation masonry labour	1	R4 000,00	R4 000,00
floors labour	1	R2 000,00	R2 000,00
140 mm maxi brick	7000	R5,00	R35 000,00
Brick Transport	4	R720,00	R2 880,00
			R43 880,00
WEEK 3			
SUREBUILD CEMENT 42.5 SOKG YARD	28	96.00	R2 688,00
PLASTER KEY 25LT	1	1150.00	R1 150,00
BRICKFOR CE NHBRC 75X2.8MMX20M	22	48.00	R1 056,00
BUILDERS BALL VALVE LEVER FXF 20MM	1	128.00	R128,00
Steel WINDOW Frame 1500X1200	4	749.50	R2 998,00
Bathroom WINDOW 600X900 1V BRZ	1	R600,00	R600,00
MAXI LINTEL 75X140MM 1.2M	5	60.00	R300,00
MAXI LINTEL 75X140MMX1.8M	4	120.00	R480,00
D/FRAME DBL REBATE STL 813X2032X115 R/H	5	640.00	R3 200,00

DPC 225X40X375 MIC SABS	1	99.00	R99,00
GALV WIRE 3.15MMX5KG	2	150.00	R300,00
Air bricks	5	R20,00	R100,00
Transport	2	R720,00	R1 440,00
			R14 539,00
WEEK3/4			
Brick work/masonry	4 room and bathroom	R18 000,00	**R18 000,00**
WEEK 5			
TIMBER SAP U/TRT 38X114X6.6M	10	175.00	R175,00
TIMBER SAP U/TRT 50X76X6.6M	12	180.00	R2 160,00
CORR IRON 0.47MMX3.6M GALV Z150	22	R450,00	R9 900,00
B/PRIDE ROUND WIRE NAILS 75X3.55MM 1KG	4	35.00	R140,00
B/PRIDE ROUND WIRE NAILS 100X4MM 1KG	4	35.00	R140,00
B/PRIDE ROOF SCREWS 90MM PK100	3	100.00	R300,00
Roofing Labour	1	R3 000,00	R3 000,00
Transport	1	R720,00	R720,00
			R16 535,00
WEEK 6			
DOOR MIXED TIMBER 8 PANEL STABLE	5	1499.00	R7 495,00
door handles	5	R120,00	R600,00
Window seals	13	R20,00	R260,00
1 x 5litre Door Varnish	1	280.00	R280,00
windows Glass	4	R350,00	R1 400,00
Bathroom window glass	1	R100,00	R100,00
PLASTER SAND YD P/M3	1	R395,00	R395,00
SUREBUILD CEMENT 42.5 SOKG YARD	4	R96,00	R384,00
Door installation Labour	5	R300,00	R1 500,00
windors/ doors Plastering Labour	8	R200,00	R1 600,00
Window glass installation	4	R250,00	R1 000,00

Bathroom Tiling labour	1	R1 000,00	R1 000,00
Tiles(2x 8m3)	0	R0,00	R0,00
Mosaic shower tiles 9 0 0 450 R50 (6 pak)	0	R0,00	R0,00
Mosaic tiles adhesive (500ml Bucket)	0	R0,00	R0,00
Tile cement	0	R0,00	R0,00
tile grout & spacers 5kg	0	R0,00	R0,00
			R16 014,00
WEEK 7			
Bathroom Material			
BUILDERS MIAMI C/C T/F 200 WHT	1	1095.00	R1 095,00
PVC SV JUNCTION PLN SGL 95 110MM SY41	4	R164,00	R656,00
PVC UG BEND PLN SP/SOC 1/16 110MM UB40	4	R117,00	R468,00
PVC UG RODDING EYE 45 110MM UAP43	2	R101,00	R202,00
LUBRICANT PVC SOFT SOAP SLT	1	R81,90	R81,90
PVC PIPE UG SABS 100KPA 110MMX6M CREAM	6	R245,00	R1 470,00
PVC SV JUNCT IE SNGL 135 110MM SY400	2	R249,00	R498,00
PVC SV BEND VENT HORN IE 110MM SB400	2	R144,00	R288,00
FLEXIBLE PAN CONNECTOR	1	R120,00	R120,00
VENT VALVE 2 WAY	1	R152,00	R152,00
P TRAP RES@AL 40MMX40MM	1	R62,00	R62,00
DEN BRAVEN 1001 DIY SILICONE 260ML CLR	1	R24,50	R24,50
JUNCTION PVC 50MMX135MM PLN SV	1	R16,10	R16,10
BUILDERS SHOWER TRAP SOMM	1	R45,00	R45,00
PVC WASTE BEND PLN 87.5 COMM WBE50	2	R17,00	R34,00
PVC WASTE BEND IE 135 COMM WBE53	2	R23,00	R46,00
BUILDERS ASPIRE SHOWER MIXER	1	R625,00	R625,00
BUILDERS ASPIRE BASIN MIXER	1	R675,00	R675,00
BUILDERS COPPER ELBOW 90D 15MM	25	R6,00	R150,00
BUILDERS COPPER TEE EQUAL 15MM	10	R10,00	R100,00

TOPLINE SOLDER RESIN CORE 100G	1	R180,00	R180,00
NASCO FLUX 75G	1	R40,00	R40,00
GAS CARTRIDGE 190G	2	R25,90	R51,80
BUILDERS COMP ELBOW CXMI 15MM	6	R30,00	R180,00
BUILDERS ANGLE VALVE DR 1/2X1/2 SILV	3	R60,00	R180,00
BRAIDED CONNECTOR 200MM 1/2 F F	3	R50,00	R150,00
BUILDERS COPPER ELBOW 45D 15MM	25	R8,00	R200,00
BUILDERS SHOWER ROSE PLASTIC	1	R136,50	R136,50
BUILDERS SHOWER ARM 350MM	1	R250,00	R250,00
PVC SV BEND PLAIN 95 110MM SB40	2	R72,00	R144,00
SUPERLINE DUAL GEYSER 150LT	1	R3 650,00	R3 650,00
BUILDERS PCV 600KPA + 2 VACUUM BREAKERS	1	R699,00	R699,00
COPPERTUBE 460/0 22MMX5.5M SABS	2	R500,00	R1 000,00
BUILDERS COPPER ELBOW 90D 22MM	2	R12,00	R24,00
BUILDERS COPPER ELBOW 90D CXMI 22MM	1	R33,00	R33,00
ISCA BALL STOP 15MM FE 5010CHP	1	R147,00	R147,00
BUILDERS COPPER COUPLER RED 22X15MM	1	R12,00	R12,00
COPPERTUBE 460/0 15MMX5.5M SABS	6	R275,00	R1 650,00
SOLO BASIN DROP—IN BAKOVEN WHT	1	R665,00	R665,00
BETTA CLASSICO PEDESTAL WHT	1	R435,00	R435,00
BUILDERS COMP COUPLER STR CXMI 15MM	6	R21,00	R126,00
ASTORE COMP ELBOW 32MM BLK AND BL	2	R49,00	R98,00
ASTORE COMP FE TEE 20MMX3/4INCH	2	R45,00	R90,00
BUILDERS GATE VALVE FXF RB 20MM	2	R165,00	R330,00
PVC PIPE SV WHT 50MMX6M E SPEC	1	R153,00	R153,00
PVC PIPE UG SABS 100KPA 110MMX6M CREAM	2	R245,00	R490,00
HDPE PIPE 20MM PE100 PN16 P/M	15	R10,00	R150,00
Plumbing	Plumbing Labour	R5 000,00	R5 000,00

Electical material			
CRABTREE SGL SOCKET 4X4 6897N LSE	2	R80,00	R160,00
CRABTREE SGL SOCKET 4X4 6897N LSE	1	R80,00	R80,00
E/PRIDE LAMPHOLDER NYLON BATTEN BLK BC	6	R18,00	R108,00
NUR DB BOARD MINI RAIL SURFACE 8 WAY	1	R1 050,00	R1 050,00
BUILDERS SWITCH STL 1 LEVER WHT	2	R49,00	R98,00
BUILDERS SWITCH STL 2 LEVER WHT	2	R60,00	R120,00
WALL BOX 100X50MM GALV	5	R6,00	R30,00
WALL BOX 100X100MM GALV	5	R7,00	R35,00
CRABTREE SGL SOCKET 4X4 6897N LSE	2	R80,00	R160,00
HOUSE WIRE 2.5MM 100M BL ROL	1	R840,00	R840,00
HOUSE WIRE 2.5MM 100M RED ROL	1	R350,00	R350,00
HOUSE WIRE 2.5MM 100M GRN ROL	1	R840,00	R840,00
HOUSE WIRE 2.5MM 100M BL ROL	1	R840,00	R840,00
SADDLES GALVANISED 20MM 20PK	5	R35,00	R175,00
E/PRIDE PVC CONDUIT 4M 20MM	25	R19,00	R475,00
PVC ROUND BOX 4 WAY 20MM	8	R12,00	R96,00
NITTO TAPE RED	2	R12,00	R24,00
NITTO 21 PVC TAPE - BLACK	2	R17,00	R34,00
CBI CIRCUIT BREAKER 35A 2.5KA	1	R151,00	R151,00
CBI CIRCUIT BREAKER 20A 2.5KA	3	R113,00	R339,00
CBI CIRCUIT BREAKER 10A 2.5KA	1	R113,00	R113,00
CBI CIRCUIT BREAKER 60A 2.5KA QA-1(1	1	R131,00	R131,00
CBI EARTH LEAKAGE 63A OVERLOAD PROTECT	1	R1 753,00	R1 753,00
CRABTREE DBL SOCKET 4X4 VERT CT6881 LSE	2	R120,00	R240,00
FLAT TWIN EARTH 1.5MM 100M WHT ROL	1	R990,00	R990,00
FLAT TWIN EARTH 2.5MM 100M WHT ROL	1	R1 500,00	R1 500,00
E/PRIDE PVC ADAPTOR MALE 20MM 10PK	5	R22,00	R110,00
E/PRIDE PVC COUPLING 20MM SOPK	1	R60,00	R60,00
BUILDERS MIAMI C/C T/F 200 WHT	1	R1 095,00	R1 095,00

PVC SV JUNCTION PLN SGL 95 110MM SY41	4	R164,00	R656,00
Transport	1	R720,00	R720,00
Electrician Labour	1	R3 000,00	R3 000,00
			R39 445,80
WEEK 8			
F/EARTH PAINTER S PRO PLASTER PRM WB 20LT	4	R599,00	R2 396,00
BUILDERS ROLLER PVA & BRUSH SET 225MM	4	R110,00	R440,00
POWAFIX PARAFFIN SLT	8	R198,00	R1 584,00
OVERTILE FLASHING 175X50MM 1.8M	8	R83,00	R664,00
ABE SUPER LAYKOLD 20LT BLK	1	R829,00	R829,00
Painting Labour	4,5	R400,00	R1 800,00
Project management Fee	1	R10 000,00	R10 000,00
			R17 713,00

Appendix 3 – Ethics Clearance

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG | SCHOOL OF ARCHITECTURE PLANNING

04 October 2021

Faculty of Engineering and the Built Environment:

Ethics clearance letter:

Dear Maphumulo, Minenhle Yvonne Desiree (753493), this letter confirms that your ethics application has been cleared. Your clearance/protocol number is SOAP121/06/2021

Yours sincerely

Lerato Nkosi

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