SANDBAG BUILDING TECHNOLOGY

Abimbola Windapo, Johnson Adetooto, Francesco Pomponi and Fidelis Emuze

About the Book

A literature review of available 'local' and 'imported' building materials and a survey of selected building and construction companies in South Africa revealed that the Sandbag Building Material is the most widely used local building material in South Africa. At the same time, it was found out that there was a lack of awareness of the technology for its construction its physical or environmental properties. Hence, this book focuses on Sandbag Building Technology for affordable housing construction. It introduces the reader to the Sandbag Building Technology, history, types and physical properties. It provides an overview of the various construction methods of the Sandbag Building Technology and the extent of its use. The benefits of using the Sandbag Building Technology as an alternative to conventional housing construction methods, economic and environmental benefits of the technology, its comparative advantage and drivers and barriers to its acceptance in housing construction is also covered in the book. Finally, the book proposes strategies for improving the uptake of the technology in housing construction and its introduction into the Construction Management and Engineering Curriculum.

Mr. Gamelihle Sibanda
Reviewer/Editor

February 2022

Published by the Construction Business and Management Research Group,
Department of Construction Economics and Management,
Level 5, Snape Building,
University of Cape Town,
South Africa.

ISBN No: 978-1-998962-05-1

Research Sponsors

ROYAL ACADEMY OF ENGINEERING

NRF National Research Foundation

Research Collaborators

University of Cape Town • iYunivesithi yaseKapa • Universiteit van Kaapstad

Edinburgh Napier UNIVERSITY

Central University of Technology, Free State

NATIONAL HOME BUILDERS NHBRC REGISTRATION COUNCIL

ubu

About the Authors

Abimbola Windapo: Abimbola is a Professor of Construction Management at the University of Cape Town, South Africa, a Fellow of the Nigerian Institute of Building (NIOB), a Registered Builder with the Council of Registered Builders of Nigeria (CORBON), and a Registered Construction Project Manager with the South African Council for the Project and Construction Management Profession (SACPCMP). She has more than 30 years of experience in the construction industry. She has practised, written, lectured, and researched building regulations, construction innovation, planning, contractor development, and project performance.

Johnson Adetooto: Johnson graduated with First Class Honours from the Department of Building at the Federal University of Technology Akure, Nigeria, in 2018. He is enthusiastic about research and academics, and he has two years of experience teaching and researching in respected Nigerian universities. He is currently a National Research Foundation (NRF) scholar and a Master's of Philosophy research student at the University of Cape Town's

Department of Construction Management, with a research focus on "Investigation of the Social Acceptability and Extent of Use of Alternate Building Technologies in Housing Construction in South Africa."

Francesco Pomponi: Francesco is Professor of Sustainability Science at Edinburgh Napier University, where he heads the Resource Efficient Built Environment Lab (REBEL). His academic expertise lies in life cycle assessment, embodied and whole life carbon, and the circular economy. His work revolves around low-carbon buildings, measurement, management and mitigation of environmental impacts, and passive design within the built environment. He has authored over 100 peer-reviewed publications and secured more than £1.5M in funding from the EPSRC, the Royal Academy of Engineering, UKRI, Innovate the UK and the EU. He is an Editor of Elsevier's Sustainable Production and Consumption and editorial board member of various international journals.

Fidelis Emuze*:* Fidelis is a Professor and Department Head in the Department of Built Environment at the Central University of Technology, Free State. Fidelis is a Research Associate in Construction Management at Nelson Mandela University (NMU) and the Coordinator of CIB W123 – People in Construction. He is a reviewer for 36 international journals. Fidelis has also assessed 59 masters and doctoral reports (treatise/dissertation/thesis) from Africa, Australia and New Zealand. Fidelis is an ordained minister in the Redeemed Christian Church of God.

Acknowledgment

The authors wish to gratefully acknowledge the Royal Academy of Engineering, UK, under the Industry-Academia Partnership Programme (Grant No. IAPP 18/19 - 215), the Distinguished International Associate Award, and the National Research Foundation (NRF) in South Africa for their financial support in conducting this study. Opinions and conclusions are those of the authors and are not necessarily attributable to the Royal Academy and NRF.

The authors also acknowledge the University of Cape Town, University of Edinburg Nappier University and Central University of Technology Free State for their collaborative effort on the book.

The authors special acknowledged Barry Lewis for his contribution and Gama Sibanda for the review of this book.

Table of Contents

List of Figures

List of Tables

List of Abbrevations and Acronymns

ABT – Alternative building technology

CoCT – City of Cape Town

NHBRC- National Home Builder's Registration Council

SAHIF - South African Housing Infrastructure Fund

SBT – Sandbag building technology

SRC – Steel renforced concrete

1.0 Overview of Alternative Building Technology

1.1 Introduction

This chapter gives an overview of the alternative building technology in South Africa, and it explores its housing delivery landscape. It presents the need for alternative housing delivery and an overview of the extent of the use of building materials and technologies in housing delivery in South Africa**.**

1.2 The housing delivery landscape

Housing is a fundamental need of humans. Housing provides essential security, safety, and shelter needs. Adequate and affordable housing plays a vital role in tackling poverty and improving the standards of living and health conditions (Adabre et al., 2020). For instance, Pollack et al. (2010) showed that most of the declining public health issues in the United States were partially linked to inadequate access to affordable housing. Adequate and affordable housing is imperative to reducing unemployment in a nation because most sectors of the economy (commerce, manufacturing, and finance) benefit from the booming housing sector (Adabre et al., 2020). However, realising some of these benefits of housing for low-income earners in both developed and developing countries is almost impossible, as providing affordable housing to lower and medium-income families is a significant issue (Adabre et al., 2019; Moghayedi et al., 2021). For instance, in developed countries, a certain percentage of their population was noted as homeless; Australia (0.471%), Canada (0.435%), Chile (0.071%), Denmark (0.095%), and Ireland (0.083%) (Golubchikov et al., 2012; Adabre et al., 2019). The lack of affordable housing directly causes homelessness and the formation of slums (See Figure 1). For instance, while Alaazi (2019) notes that Sub-Saharan Africa has the most urban slum dwellers, Golubchikov (2012) estimated that 199.5 million people dwell in urban slums in sub-Saharan Africa.

More so, in South Africa, it is estimated that 12.5 million families are living in slums without access to adequate housing (Human Settlements Review, 2010, 2015 and 2018). Previous research established that the housing deficit in South Africa presently stands at about 2.2 million units (National Home Builder's Registration Council 2020; Ncube, 2017). For instance, in the City of Cape Town, The Cape Metropolitan MSDF of 2018 has projected a housing demand of 500,000 housing units over 20 years (2012-2032) (CoCT, 2018). Based on the available resources, it is estimated that it will take more than 70 years to eliminate Cape Town's current housing backlog (CoCT, 2018). Therefore, achieving sustainable and affordable housing solution remains a pressing goal.

Figure 1: South Africa Housing overview

Note: (a) Homelessness in South Africa (Perlman et al., 2021); (b) Inadequate housing condition in South Africa (Socio-Economic Rights Institute (SERI) of SA 2018

1.3 Need for alternative building technology

The South African government and scholars view Alternative Building Technologies (ABTs) as a veritable approach to constructing quicker, sustainable, affordable housing with better quality (National Home Builder's Registration Council 2020; Ncube, 2017; Dosumu and Aigbavboi, 2019). Alternative Building Technology can be defined as any expertise, skill, knowledge, equipment, machinery, or tools other than conventional ones to accelerate housing delivery without compromising the quality and durability of any erected structure (Tshivhasa and Mbanga, 2018). ABTs are also referred to as non-conventional building methodologies that utilise economically valuable and environmentally friendly building materials to deliver affordable houses (South African Housing Infrastructure Fund, 2020). De Villiers and Boshoff (2012) established that ABTs are sustainable, affordable, and faster building construction methods.

Despite the advantages of ABTs and their potential to bridge the housing deficit in South Africa, their adoption in housing construction is low. Botes (2013) and Salzer et al. (2016) found that conventional brick, concrete and steel houses are most preferred and considered modern by an average person. South Africans perceive that houses constructed with ABTs were only meant for the poor. They expressed their preference to live in a house built with conventional materials; brick, concrete blocks, and mortar (Grady et al., 2019; and Aigbavboa and Thwala, 2018). This is evident as the preponderance of the South African built fabric is made up of conventional material, which includes bricks, concrete blocks and mortar (Schmidt et al. 2013, Dlamini 2020).

1.4 Alternative Building Materials in South Africa

Preponderances of South Africa built fabrics are made of conventional materials. Seventy-eight per cent of government-built houses were made from bricks, and nearly 20% were constructed from concrete blocks (Marais, 2014). According to Bosman et al. (2014), as shown in Figure 2, the adoption of alternative building material accounted for a combined usage rate of slightly over two per cent.

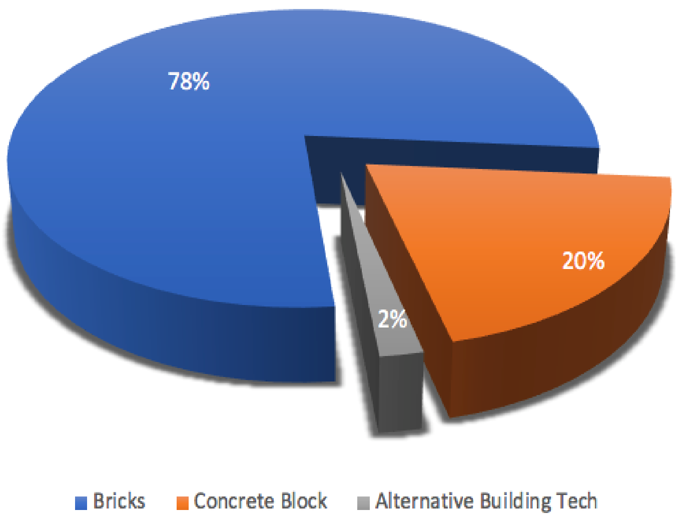

Figure 2: South Africa building material statistics (Marais, 2014)

The housing deficit in South Africa is associated with a lack of appropriate building technology in delivering adequate housing (Ncube 2017). Feder et al. (2020) acknowledge that the Government of South Africa through various interventions and program encourages the use of various alternative building technologies, new building materials, and construction techniques to deliver several low-cost housing projects in South Africa.

There are a number of alternative building technologies in South Africa, including moladi (lightweight plastic formwork mould), sandbag/earthbag, jumbo blocks, and Hydraform (NHBRC 2020). However, this book focuses on sandbag technology, because previous research established that it has better economic and environmental advantages over other alternative building technology in delivering low-income housing in many countries (Cataldo-Born et al., 2016; Hadjri et al., 2007) and previous research found it was the most used but unknown Local Building Material Technology in South Africa.

2.0 Sandbag Building Technology

2.1 Introduction

This chapter provides an overview of the Sandbag Building Technology. It explores the history of the housing delivery landscape in South Africa, it provides a detailed overview of the various categories of Sandbag Building Technology and its structural properties. Finally, it presents an overview of the cost analysis, method of construction, and the extent of use of the technology in housing delivery.

Sandbag/earthbag technology is an earthen architecture that employs locally available soil combined with woven bags filled and stacked to form a building (Rincon, 2019). The sandbag is also known as an earthbag, superadobe, or superblock. It is an alternative building technology that utilises relatively inexpensive, locally available, and naturally occurring materials (Kennedy and Wojciechowska, 2005). The technology consists of walls built with stacked bags filled with sand, interspersed with barbed wire to improve the adherence between layers (Hunter; 2004; Minke, 2006; Santos and Beirao, 2017).

2.2 History of Sandbag Building Technology

Sand-filled bags have been widely used since the 17th century for military defence and flood protection. They have also been used in soil retaining walls and embankments to increase the bearing capacity of the footings (Cataldo-Born et al., 2016). The military used the sand-filled bag to create bunkers and barriers for protection before World War I because sand-filled bags are easily assembled and can effectively ward off bullets (see Figure 3).

Figure 3: Sand-filled bags military bunker (Leiden 2011)

SBT is an earthen architecture that uses locally available soil placed in woven bags filled and stacked to form a building (Rincon, 2019), as shown in Figure 4.

Figure 4: Sandbag stacked bags

Innovation in Sandbag Building Technology (SBT) for building houses and permanent structures was pioneered by Architect Nadar Khalili of the California Institute of Earth Art and Architecture in 1990 (Kennedy, 2002). In 1986, Architect Nadar Khalili started research focussing on finding ways to build a house on the moon using local building materials (Khalili 1989) in response to the call from the National Aeronautics and Space Administration (NASA).

Khalili later broadened the scope of his work to include solving the social housing deficit by building houses for the homeless in the United States with local building materials - earth, sands, and mud (Minke 2013; Hunter and Kiffmeyer 2004). This innovation was borne out of a passion for providing affordable housing for millions of refugees and victims of wars and disasters in the early 90s (Surhone et al., 2010). Khalili discovered Sandbag Building Technology as a good option for building houses for the poor and on the moon (Sharma 2015 and Khalili 2014).

Khalili developed a sandbag building prototype, presented to NASA as “Velcro-adobe”. The patented (U.S. Patent #5,934,027) and trademarked (#3,195,445) technology is offered free and licensed for commercial use (Holgate, 2003). This prototype won the Aga khan Award in 2004 (Khalili 2014).

Khalili's research served as a model for other research institutions and has received growing research attention in the past decade. Kamal and Rahman (2018) noted that

SBT is slowly gaining worldwide recognition as an optimum solution to the global epidemic of housing shortages. The sandbag building technologies are available in various shapes - curvy, linear, and dome walls, with the wall colour, length, and textures.

Figure 5: History of Sandbag (Source: Leiden 2011)

2.3 Categories of the Sandbag Building Technology

Sandbag Building Technology can be classified based on the size of the bags. There are two main categories of Sandbag Building Technology which include the earthbag/sandbag and the superadobe (Rincon et al., 2019). Both earthbag and superadobe construction involves introducing earth and a small amount of binder in the bag to confine the filling. The bags are placed and stacked together to form a wall, sometimes barbed wire is introduced to improve friction and adhesion between the stacked bags (Kennedy, 2002, Rincon et al., 2019). Also, both the superadobe and earthbag come in various shapes and sizes.

2.3.1 Superadobe

Superadobe is a form of sandbag building technology that uses a long continuous bag to contain soil (Rincon et al., 2019). Superadobe was developed and patented by architect Khalili in 1999 (Khalili 1999).

(a)

Figure 6: Superadobe

(b)

Note: (a) superadobe under construction (b) completed superadobe house

2.3.2 Sandbag/Earthbag

Sandbag/Earthbag is a form of sandbag building technology that uses a short regular degradable bag to contain soil (Rincon et al., 2019). Figure 7 shows the sandbag house under construction.

(a)

(b)

Figure 7: Sandbag house under construction

2.4 Sustainable Affordable Housing

A sustainable, affordable housing concept (SAH) is "housing that meets the needs and demands of the present generation without compromising the ability of future generations to meet their housing needs and demand" (Pullen et al., 2010). Sustainable Affordable Housing (SAH) provides an economic benefit and improves occupant health, comfort, energy, and water efficiency while also reducing cost (Sullivan and Ward, 2012; Golubchikov and Badyina, 2012). It is possible to achieve an 80% reduction in energy through a suitable practice (Adabre et al., 2020). Affordable housing is when a household spends less than 30 per cent of its income on housing (Friedman and Rosen, 2018). A house is sustainable when it is of good quality, in a good location for a lower-middle-income household, and the cost is reasonable to allow a household to meet other basic living costs on a sustainable basis (National Summit on Housing Affordable, 2006).

Sandbag building technology provides economic and environmental advantages in delivering affordable houses in many developed and developing countries. It is an earthen architecture that uses locally available soil placed in woven bags filled and stacked to form a building

(Rincon, 2019). Houses constructed with sandbag building technology consume less energy during construction and operations (Hunter & Kiffineyer, 2004; Cataldo-Born et al., 2016) than conventional building technologies. It also regulates the internal temperature of the building by absorbing excess heat during the day and releasing it at night, thereby providing a relaxed internal environment in hot and warm weather (Rincón et al., 2019; Shaker et al., 2017; Santos and Beirão, 2016). More so, economically, sandbag technology is relatively cheaper than conventional technologies.

In 2016, Cataldo-Born et al. (2016) recorded fifteen thousand sandbag houses in the world. Countries including United States, Australia, Brazil, India, Iran, Haiti, and Chile have adopted earthbag construction to deliver sustainable, affordable, low-income, and modern homes (Rincon et al., 2019). According to Geiger and Zemskova (2015) Sandbag technologies are well established in the US building code.

Sandbag technologies has been used to deliver houses in some African countries however, its adoption is still very low in Africa (as shown in Figure 8). For example, sandbag technology has been used in the construction of low-income residential building in Rwanda (McIntosh, 2019), an emission training medical centre in Ouagadougou in Burkina Faso (Rincon et al., 2019), a one-bedroom prototype building in Egypt (Shaker et al., 2017) and a pavilion and low-cost houses in South Africa (Grady et al., 2019; Santos and Beirão, 2016).

The comprehensive implementation and level of adoption of the sandbag building technology are still very low in South Africa even though researchers and manufacturers view that adopting ABTs such as sandbag building technologies is crucial to solving the housing deficit in South Africa by delivering sustainable and affordable housing,

Figure 8: Houses constructed using sandbag technologies in Africa

Note: (a) Rwanda sandbag house construction (Survant, 2014); (b) Burkina Faso sandbag house construction (Rincon et al., 2019); (c) Egypt sandbag house construction (Dabaieh and Said, 2013); (d) Sandbag pavilion in Johannesburg; and (e) Sandbag house in Cape Town (Calburn, 2010.)

2.5 Cost analysis of Sandbag building

The approximate cost per square meter of a sandbag house in India and South Africa is estimated at 7.55 and 242 US dollars respectively (Ecobuilder, 2019). Figure 29 and Table 1 show a 42m^2 house and list the items used in the construction of the house with the estimated costs (Sales info, 2019). It was estimated that the house could be built for R 145 236.

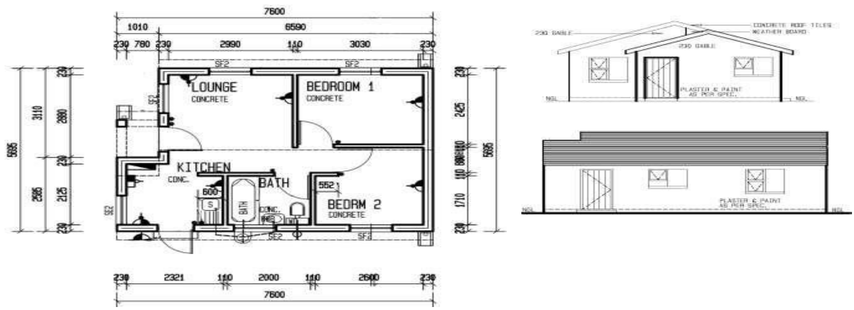

Figure 9: Floor plan and Elevation of Sandbag house (source: Ecobuilder, 2019)

Table 1: Cost analysis of a sandbag house

Soil Poisoning	R	10 m²
Raft Foundation @ R 480 m²	R	480 m²
Number of bags 3600 including courier cost	R	207 m²
Supply of sand and filling of the bags	R	178 m²
Laying of the bags @ 600 bags per day per labourer	R	65 m²
Timber battens 38mm x 38mm @ R 10 per linear metre	R	96 m²
Spacers 159mm (L) x 114mm (H) @ R 30 p/linear metre	R	78 m²
Manufacturing 50 timber frames per day with 2 labourers	R	35 m²
Erection of timber framework on site	R	22 m²
Steel window frame & glass	R	185 m²
Steel door frames & timber doors	R	169 m²
23.02 metres x 180mm ring beam	R	197 m²
Plastering the wall surface area of 198.775m²	R	520 m²
Steel roof truss & concrete tiles	R	352 m²
Electrical includes geyser	R	226 m²
Plumbing (Shower, toilet, handwash + kitchen unit)	R	238 m²
Floor tiling (tiled throughout the house)	R	150 m²
Painting (includes undercoat & waterproofing)	R	90 m²
PVC Ceilings	R	160 m²
Cost per m^2	R	3 458 m²

3.0 Benefits of Sandbag Building Construction

This chapter gives an overview of the Benefits of Sandbag Building Technology which include the economic and environmental benefits and explores the various barriers and drivers to the acceptance of sandbag technology.

3.1 Benefits of Sandbag Building Technology

SBT provides economic and environmental advantages in delivering affordable houses in many developed and developing countries. Sandbag building materials are viewed as non-conventional materials (Rincon, 2019).

3.1.1 Economic benefit

Construction of a new building in South Africa is expensive and it sometimes requires a lifetime mortgage from homeowners. Hence, most people seek affordable self-sustaining construction alternatives due to the cost of building new houses (Freney, 2014). Previous research by Ben-Alon et al. (2020), Cataldo-Born et al. (2016) and Geiger and Zemskova (2015) affirmed that sandbag technology is one of the least expensive construction technologies globally; establishing that it utilizes occurring natural materials and uses cheap labour and that a typical sandbag house might cost 7.55 US dollars per square meter compared to 20.75 US dollars per square meter for a concrete block in India.

3.1.2 Environmental benefit

According to Hunter and Kiffineyer (2004); and Cataldo-Born et al. (2016) houses constructed with sandbag building technology consume less energy during construction and operations. Various researches affirmed that Sandbag Building Technology emits less Green House Gases (GHG) than the traditional construction techniques throughout its life cycle (Ben-Alon et al., 2020; Christoforou et al., 2016; Freney, 2014; and Treloar et al., 2001). According to Daigle et al. (2011), Sandbag technology has lower embodied energy than other building technologies, and it requires low energy during winter (Hunter & Kiffineyer, 2004; Kennedy & Wojciechowska, 2005; Wojciechowska, 2001) and hence, reduce heating cost (Sharma 2015).

It also regulates the internal temperature of the building by absorbing excess heat during the day and releasing it at night, thereby providing a relaxed internal environment in hot and warm weather (Rincón et al., 2019; Shaker et al., 2017; Santos and Beirão, 2016). A preliminary life cycle assessment (LCA) of the solution presented in this book has been conducted with a cradle-to-site system boundary showing promising results in terms of greenhouse gas (GHG) emissions linked to the sandbag housing construction technology.

Depending on whether manual or mechanical exaction results range from 150 – 165 kg CO_2e/m^2. This is at least 20% lower than alternative solutions in terms of environmental impacts and contribution to climate change and global warming. Additionally, more than half of the impacts of the sandbag housing are linked to the concrete used in the foundations and constructions. Forms of low carbon concrete, or alternative materials in that area too would significantly reduce the environmental impact further.

3.2 Barriers to Sandbag Building Technology use

A comprehensive literature search identified 20 barriers hindering the uptake of sandbag building technologies in housing construction. The identified barriers were further categorized into four groups: professional-related barriers, government-related barriers, client related barriers, and investor-related obstacles as shown in Figure 10.

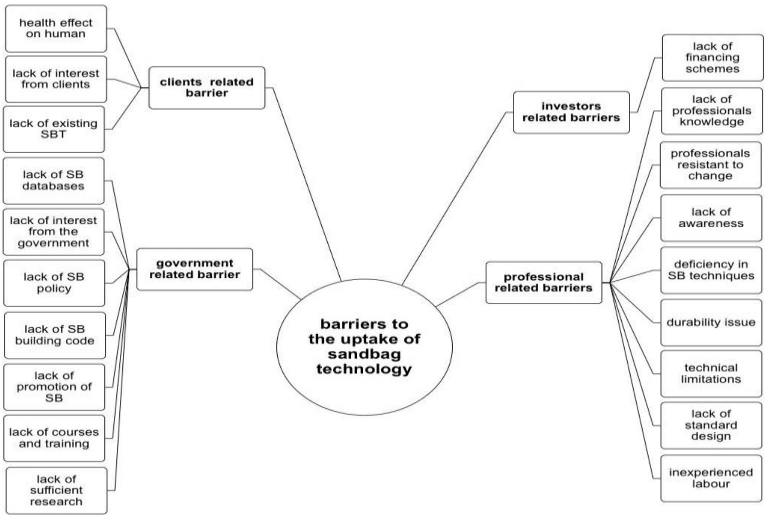

Figure 10: Barriers to sandbag technology uptake

3.2.1 Government related barriers

Previous research has established that leaders of developing countries do not support earthen material such as sandbag technology, as they are reluctant to build houses using regular soil (Ben-Alon et al., 2020; Santos and Beirão, 2016). This is also evident in the lack of government policy to support the adoption of alternative building technologies such as sandbags (Mpakati-Gama et al., 2012 and Hadjri et al. 2007). Unlike conventional technologies, there are no general building codes or recommendations for alternative building technologies, especially the use of sandbags (Cataldo-Born et al., 2016 and Sharma 2015). Zami and Lee (2011) view that governments of developing countries are not interested in the ABTs, as most of the technology promotion is done by foreign agencies.

3.2.2 Professional-related barriers

Extant studies are of the opinion that most construction professionals (architects, engineers and constructors) lack adequate knowledge, skill, and understanding of ABTs (Leveraging, 2017; Santos and Beirão, 2016). Some professionals posit that ABT is more expensive than conventional building methods and knowledge (Grady et al., 2019). According to Grady et al. (2019) and Oguchukwu (2015), most professionals prefer to use traditional building materials and technologies because they are familiar with them.

Previous research argued that professionals are not confident in the ability of the earthbag to withstand the appropriate loads with minimal deformation; hence, the lack of technical limitations of these alternative building techniques is a significant barrier to the acceptance of the professional (Cataldo-Born et al., 2016; Barros & Imhoff, 2010 and Vardy et al., 2006).

3.2.3 Client-related barriers

Leverage (2017) noted that most people do not have adequate knowledge and understanding of ABTs. Daige et al. (2010) also viewed that the average South African person has a cultural preference for a house built with concrete and brick. Grady et al. (2016) found that many South Africans believe that ABTs are meant for the poor.

3.2.4 Investor-related barriers

Leverage (2017) noted that many investors are unfamiliar with the technology and efficiency of ABTs. Therefore, accessing housing credit and insurance from financial institutions is almost impossible. (Zami and Lee, 2011; Norton, 1997). It is also difficult to get financial support (bank loans, government subsidies, grants, etc. (Adegun and Adedeji, 2017).

3.3 Drivers of Sandbag Building Technology use

A comprehensive search strategy to determine the benefit and drivers of Sandbag technology uptake conducted on PubMed, Scopus, and Google Scholar search engine resources (from inception till 2021) found that the top drivers of the uptake of sandbag building technology are:
High energy efficiency, affordability, and better thermal comfort.

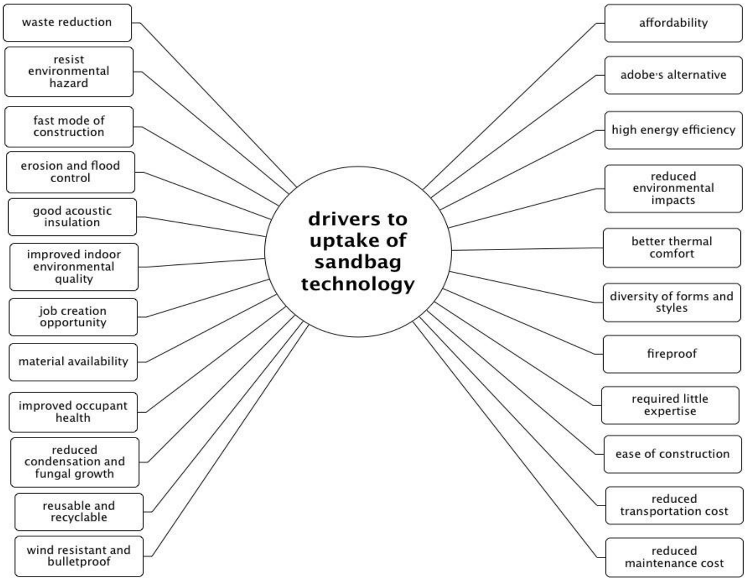

Figure 11: Drivers of Sandbag Technology uptake

3.3.1 High energy efficiency

Extant studies established that houses constructed with sandbag building technology consume less energy during their construction process and operations (Cataldo-Born et al., 2016). Various researches affirmed that sandbag building technology emits less Green House Gases (GHG) than the traditional construction techniques throughout its life cycle (Ben-Alon et al., 2020; Christoforou et al., 2016; Freney, 2014; and Treloar et al., 2001). According to Daigle et al. (2011), Sandbag technology has lower embodied energy than other building technologies, and it requires low energy during winter; (Hunter & Kiffineyer, 2004; Kennedy & Wojciechowska, 2005; Wojciechowska, 2001) and hence, reduce heating cost (Sharma 2015).

3.3.2 Affordability

Previous research by Ben-Alon et al. (2020), Cataldo-Born et al. (2016), and Geiger and Zemskova (2015) established that sandbag technology is one of the least expensive construction technologies globally; establishing that it utilizes occurring natural materials and uses cheap labour and that a typical sandbag house might cost 7.55 US dollars per square meter compared to 20.75 US dollars per square meter for a concrete block in India.

3.3.3 Thermal comfort

Shaker et al. (2017) established that sandbag technologies have unique attributes because they regulate the internal temperature of the building, absorb excess heat during the day and release it at night. The technology is found to provide a relaxed-internal environment in hot and warm weather (Ben-Alon, et al., 2020; Rincón et al., 2019; Shaker et al., 2017; Cataldo-nBorn et al., 2016; Santos and Beirão, 2016; Sharma 2015; Daigle et al., 2011)

4.0 Recommendations for Practice

4.1 Uptake of Sandbag Building Technology

Through a comprehensive review of 11 relevant articles, 14 strategies were identified for promoting the uptake of sandbag building technologies shown in Table 2.

Table 2: Strategies to the uptake of sandbag

Code	Strategies	Related sources of data
S1	A financial incentive for sandbag uptake	Dosumu and Aigbavboa (2020).
S2	More publicity through media	Adegun and Adedeji (2017); Bobbo et al. (2015); Sameh, (2014);

	(internet; television, and radio)	Alagbe, (2010) and Hadjri et al., (2007)
3S	Public sandbag awareness creation through workshops, seminars, and conferences	Ben-Alon et al. (2020); Grady et al. (2019)
S4	Approved sandbag building code	Ben-Alon et al., (2020); Hadjri et al., (2017)
S5	Availability of the competent promotion teams and Grassroots Supporters	Ben-Alon et al., (2020); (Grady et al., 2019) and Belofsky and Zemskova (2018).
S6	Availability of sandbag demonstration projects across all provinces	Grady et al. (2019) and Hadjri et al. (2007)
S7	Availability of standard design methods for earthbag	Rincon et al. (2019)
S8	Availability of sandbag research center	Ben-Alon et al., (2020); Dosumu and Aigbavboa (2020); and Hadjri et al., (2007)
S9	Support from executive management	Belofsky and Zemskova (2018).
S10	formulation of sandbag policies and regulations	Hadjri et al., (2007).
S11	Inclusion of sandbag technology in the curriculum of technical training colleges	Lyamuya and Alam (2013)
S12	reformed tendering process	Grady et al. (2019)
S13	Standardization of the material and components	Adegun and Adedeji (2017).

S14	Educational training for investors professionals and end-user	Belofsky and Zemskova (2018).

The strategies for the uptake of Sandbag Building Technology are explained in the following sub-sections.

4.1.1 Formulation of sandbag policies and regulations

Previous research has established that the formulation ABTs, such as earthbag building codes and standards at national and international levels, is imperative to the acceptance of earthbag building methods (Ben-Alon et al., 2020; Hadjri et al., 2007). Hajiri (2007) proposed the formulation of national strategies to promote and spread the use of earth construction. They suggest that the use of publicity, research, development, training, and pilot projects to develop sustainability policies, should encourage the use of the earth as a building material.

4.1.2 Availability of demonstration projects

Extant studies believe people become more accepting of ABTs once they physically experience a house built by alternative methods (Grady et al., 2019). Therefore, to stimulate the acceptance of these alternative building methods begin by constructing a model earthbag house for community members to view, before beginning real construction on the rest of the development. Allowing community members to help build the house would also teach them about the building material and its specific construction process (Hadjri et al., 2007).

4.1.3 Availability of sandbag research centre

Extant studies promote the idea that the community will more easily accept ABTs if a building research centre is first established. In this centre, ABTs such as earthbag materials and techniques can be developed and tested, before being publicised (Dosumu and Aigbavboa, 2020; and Hadjri et al., 2007). Such a centre will provide opportunities to do new research to improve the technical performance of ABTs such as earthbags. It may also lead to collaboration, innovation, and synergy among stakeholders (Ben-Alon et al., 2020).

4.2 Incorporating alternative methods of construction such as the Sandbag Building Technology into the Construction Management and Engineering Curriculum

The integration of alternative methods of construction education and training in the construction management and engineering curricula of higher education institutions is critical for improving the knowledge, acceptance and use of alternative methods of construction such the sandbag building material technology on housing projects.

5.0 Further Reading section for practitioners.

5.1 Properties of the Sandbag Building Technology

The subject of sandbags has not been adequately explored in terms of research in the construction industry. Although there are no guidelines for sandbag construction nor testing, research has been conducted over the past decade to investigate the use of sandbags in housing and other construction purposes. For example, in Dunbar and Wipplinger (2006), no details on the material composition were provided, neither was the average bag deformation values provided, and the bag sizes were not specified. The study by Daigle (2008) used testing procedures in ASME 447 (now ASTM C1314), which was inadequate as it only relies on 3-unit stacks when testing compressive strength. This section briefly presents a review of previous studies and their findings related to the Sandbag Building Technology. The performance of sandbags is governed by both the material properties and structural properties. Material properties relate to the fill, bags and type of reinforcement used to construct the sandbag structures. In contrast, structural properties are associated with the behaviour of the sandbag structure when subjected to compression, flexural, shear or impacts.

5.1.1 Material properties of sandbags

The material properties of sandbags vary with changes in the composition of the fill. Previous studies such as Dunbar and Wipplinger (2006) did not investigate fill properties. The only tests carried out were the shear box tests done by Vadgama and Heath (2010) and Ralph (2009) on the builders' sand, which proved to have shear strength and friction angle of 76.60 kN/m^2 and 26.5^0, respectively. Though soil particles are typically divided into clay, silt, and sand, sand fills are usually preferred due to their cohesion; hence, they have been the most used fill material. However, filling made up of clay particles is particularly important since clay acts as a binding agent and has the disadvantage of expanding when exposed to high moisture levels, and an acceptable optimal range between 5% and 30% is typically used.

Daigle (2008) confirmed this by having 37% and 27% of clay and silt in the topsoil and sandy soil fill, respectively. In addition, sandbag structures are more commonly constructed using a fill material with at least 10% fines to aid compaction. While only one study (Daigle, 2008) considered large-sized particles such as crushed granite, it was found that this material resulted in early cracking or tearing of the bags.

The widely used bags for the construction of sandbags are polypropylene bags(see Figure 12).

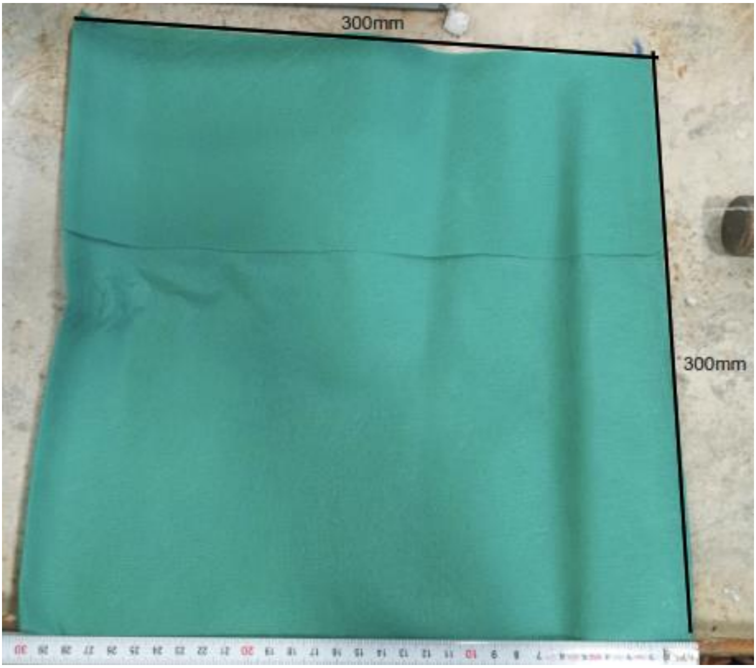

Figure 12: Empty polypropylene sandbags

These bags come in different sizes, with 20 kg as the ideal bag weight to allow individual handling during construction. The studies were undertaken by Daigle (2008), Ralph (2009), and Vadgama and Heath (2010), only tested the tensile strength of the bag material. The reasons for the variation in results between the different studies – about 19KN/m (Ralph, 2009; and Vadgama and Heath, 2010) and about 7KN/m (Daigle, 2008) is unknown but could be related to the bag thickness, size, and thread count, as well as differences in the test methods used to obtain results, all of which would need to be explored.

5.1.2 Compressive strength of sandbags

Compression tests on bag stacks, such as those carried out by Dunbar and Wipplinger (2006), Daigle (2008), Ralph (2009) and Vadgama and Heath (2010), allow the compressive strength of the sandbags to be determined. Dunbar and Wipplinger (2006) tested the soil dirt, sand and rubble-filled sandbags in a 3-bag stack, while Daigle (2008) tested crushed granite, sandy soil and topsoil-filled specimens on 3-bag, 6-bag, and 9-bag stacks, Ralph (2009), and Vadgama and Heath (2010) conducted tests on stack heights of 1, 3, 5 and 8, filled with builders' sand, in which the 8-bag stack fill material was also stabilized, and the three and 5-bag stacks were reinforced with 3-point barbwire. The studies obtained different results for the 3-bag stacks, summarized in Table 3.

Table 3: Compressive strength of 3-bag stacks, with different fill material types from various studies

Authors	Ultimate strength of different fill material types (MPa)		
	Fine soil	Medium sand	Coarse granular
Dunbar and Wipplinger (2006)	2.14	0.30	0.40
Daigle (2008)	2.33 – 2.98	2.33 – 2.98	1.27 – 1.29
Ralph (2009) & Vadgama and Heath (2010)	-	1.61	-

The fine-soil fill type includes soil dirt and topsoil, medium-sand type includes sand, sandy soil and builders' sand, and coarse-granular type include rubble and crushed granite. It is to be noted that Ralph (2009) and Vadgama and Heath (2010) experienced initial bag tearing at 1.61 MPa; however, the ultimate strength of the stacks was considered invalid due to end-restraint effects. The soil dirt-filled bags in the study by Dunbar and Wipplinger (2006) were unable to be loaded to failure (i.e., bag tearing) due to the limited capacity of the testing equipment, meaning the bag strength at failure could not be obtained. This was also observed in the study by Daigle (2008), where the soil-filled (topsoil and sandy soil) bulged but did not fail by tearing. Failure by bag tearing was observed in both the studies by Dunbar and Wipplinger (2006) and Daigle (2008) of rubble and crushed granite-filled bags. This was attributed to the coarseness and angularity of the fill material that tore the bags at lower loads.

The results obtained by Daigle (2008) were also shown to be higher than those obtained by Dunbar and Wipplinger (2006), Ralph (2009), and Vadgama and Heath (2010). A possible reason for the higher strengths could be the different fill materials used, as they differed in composition. Also, for stacks greater than three bags, Daigle (2008) obtained lower loads than Ralph (2009) and Vadgama and Heath (2010) with close-related stack heights. Like the three bag findings, the difference in results could be attributed to the different fill materials used, as Daigle (2008) used crushed granite fill and Ralph (2009) and Vadgama and Heath (2010) used builders' sand. Daigle (2008) also observed that the increase in stack height decreased the compressive strength of the sandbag stack, which was owed to the confinement caused by the loading plates, which was less impactful as the overall height of the stack increased. Ralph (2009) and Vadgama and Heath (2010) saw the same trend and considered the 8-bag stacks most relevant to minimising end-restraint effects caused by the loading plates.

Bag failure was observed as one of the failure mechanisms by different authors. Considering the 3-bag stacks, Dunbar and Wipplinger (2006) and Daigle (2008) expected the sandbags to fail by bag tearing, leading to a sudden drop in strength and compromising the integrity of the sandbag. Vadgama and Heath (2010) expected the sandbags to fail by loss in confinement or to tear the bag at the top and bottom faces due to the bag's tensile capacity being reached. In Dunbar and Wipplinger (2006)'s study, this was observed in the rubble-filled specimen, where tearing occurred in two parallel lines on the top and bottom faces of the middle bag. Daigle's (2008)'s crushed granite-filled sandbags failed by bulging, tearing the bag material.

Furthermore, Vadgama and Heath's (2010)'s sandbags failed by tearing longitudinally on the upper and lower faces of the sandbags. It is to be noted that Dunbar and Wipplinger's and, Vadgama and Heath's bags were tied the same way by twisting the open end and folding the tied end underneath the bag when stacking. Hence the same failure pattern was obtained. On the other hand, Daigle's bags were tied by folding the end and spiral screw with pins at the edges and centre of the fold.

5.1.3 Stability of sandbag walls under lateral load

The stability of sandbag walls was tested under lateral loads by Thiart (2008) and Croft and Heath (2011), who conducted flexural testing on constructed sandbag walls. Both walls were rendered with chicken wire mesh and cement plaster. Thiart's wall withstood a lateral load of 15.78 kN at failure, while Croft and Heath's wall withstood 7.32 kN. The difference between the two walls could be related to the wall size tested as Croft and Heath's wall was smaller (0.23 x 1.07 m) than Thiart's (4 x 2.5 m), which was also supported by return walls. The study by Croft and Heath (2011) also illustrated the benefit that plaster has on the wall's strength and stiffness, which were shown to be superior to those not plastered. However, the strength of the plaster might also have been contributed by the chicken wire mesh used, which would need to be explored further.

Locally in South Africa, the sandbag construction method was developed to solve the housing shortage experienced in the country due to its advantages of low energy consumption and affordability. However, there is limited research in South Africa on the structural performance of sandbags as a construction material. The studies done by Thiart (2008), Dlambulo (2009), and Herman (2009) were done to satisfy the Agrément standards in South Africa. The only similarity between these local studies and those done outside South Africa is the performance of sandbag walls under lateral loads, which was done by Thiart (2008) and discussed earlier. As mentioned before, the structural performances of sandbags walls were influenced by material and structural properties. However, in these studies, the material properties of the sandbags and fill material used were not reported, which might impact the performance of the wall. Another aspect to consider is the chicken wire mesh and plaster, whose effects on the sandbag wall were not investigated.

There is still a need for more research as the current knowledge and understanding of sandbags as a construction material is still lacking. The tests carried out in the reviewed studies showed that sandbag walls do not behave the same as brick walls. Hence, guidelines for masonry wall construction do not apply to sandbag construction, and there is a need to develop standardized guidelines and test methods for sandbag wall construction.

5.2 Methods of Sandbag Building Construction

This section will introduce readers to the materials and tools required to construct the sandbag wall, so end users can gain an understanding of the simplicity of the methodology. Figure 13 shows an example of a sandbag wall under construction.

Figure 13: Sandbag construction sample

5.2.2 Tools used for the sandbag building construction

The tools required for building an Eco Beam frame (used in framing the sandbag) are as follows (citations?):

- Jig table for the manufacture of the Eco Beams
- Hammers
- Clamps
- Sewing machine
- Cutting machine for rolls of material
- Scissors
- Electric screwdriver

5.2.3 Materials used for the sandbag building construction

The materials required to build a sandbag home (from a sandbag and EcoBeam perspective) are the following:

- Timber battens (38 x 38mm tanalised)
- Steel lattice
- Ring shank nails
- 100mm ring shank nails or 70mm chipboard screws
- Binding wire (for the bracing of the frame)
- 110/190mm tubes for filling bags
- Timber paddles (for packing bags)
- Specific thread for the bag production
- Polypropylene or similar approved material
- Sand for filling the bags

5.2.4 Sandbag Fabrication

This section presents an overview of the fabrication of the sandbag which entails sandbag production and Ecobeam fabrication.

⇒ **Sandbag production**

The bags are made from non-stretch, non-woven polypropylene fabric (60gm/m2) purchased in a 500m length roll, 330mm wide. The roll is cut at 710mm centers to make one sandbag as shown in Figure 14.

(a) (b)

Figure 14: Sandbag Production

Note: (a) 500m roll of a sandbag and (b) process of cutting the roll of bag

The panel is then folded over to make a 300mm (long) x 330 (wide) bag with a 110mm pillowcase type fold. The fold is achieved by ironing the edges very lightly. The bags are sewn with hems on the outside (so that the usable width of the bag is 300mm) and all stitching is done with a double-needle industrial sewing machine to make a ‘bag stitch’. The actual cotton used to stitch the bags is a two yarn polyester cotton blend of 120g/sqm. The strength of the cotton blend is 12(N). Elongation % min-max is 12-25 N. The bags are resistant to the alkaline environment created by the cementitious plaster and will effectively retain the sand for the life expectancy of the building. The bags are then checked for quality and then placed in stacks of 100 and bound, ready for dispatch. In one normal-sized rice bag, you can package up to 500 sandbags in five bundles.

⇒ **Ecobeam fabrication**

a. Eco-beams are fabricated of 38mm x 38mm SA pine treated timber top and bottom chords treated in accordance with the requirements of SANS 10005, and a patented, formed galvanized metal strap (40mm wide x 0.6mm thick) as web members (see Figure 15). The bending of the steel requires either a hydraulic press or a hand press with a specific dye to make the patented web member.

b. The timber sections are clamped to each side of the angle iron jig spaced 220mm apart. The angle iron jig is made up of two L-shaped sections facing each other (50mm high/wide, and 5mm thick) bolted to a table.

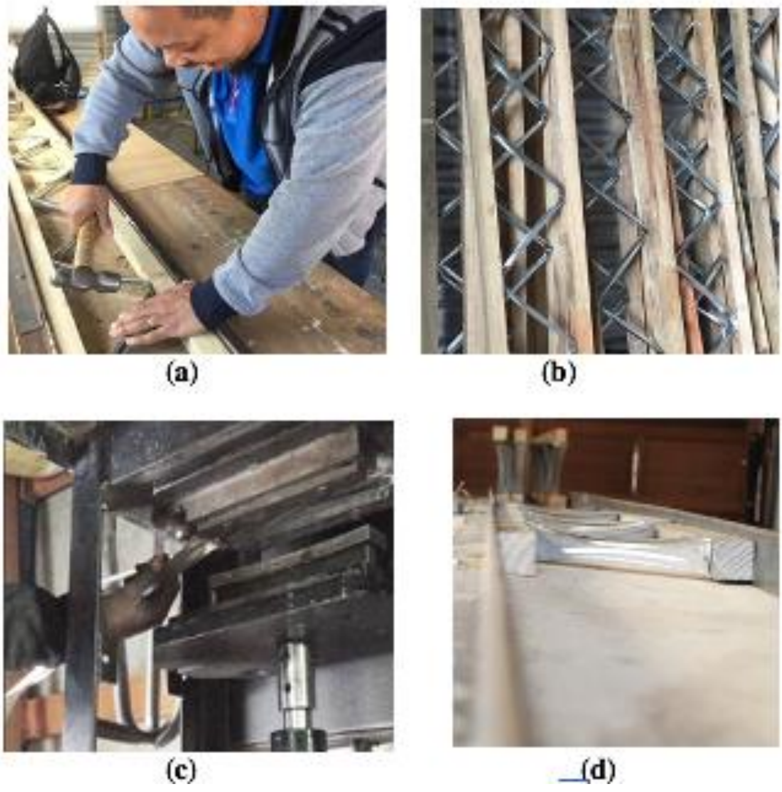

Figure 15: Ecobeam Fabrication
Note: (a) Eco beam fabrication (b) timber section (c) metal strap (d) dimensioning of beam length

c. The metal strap is bent in a zig-zag lattice pattern and nailed to the timber sections with zinc passivated ring shank nails starting from one end until the other end.
d. The beam length is dimensioned as per the particular building project. A beam schedule is produced for any specific project and beams needed for any given 'walls' are grouped together to form a frame. This frame is bundled together and delivered to the site in its number-specific bundle.

5.2.5 General construction methods

This section presents the general construction methods of the sandbag. it gives an overview of the setting out process and the foundation for the substructure and the superstructure.

5.2.5.1 Substructure

⇒ **Marking out**

The basic principles of how the footprint of the building (and corresponding foundation layout) for a sandbag building is set out are exactly the same as the conventional building as shown in Figure 16.

⇒ Foundations

Figure 16: Sandbag site marking out

Foundation and surface beds are conventional, constructed of concrete (see Figure 17), and designed by a professional engineer who classifies the site in accordance with the site class designation set out in Table 3 of the South African Institute of Engineering Geologists (SAIGE) publication entitled guidelines for Urban Engineering and Geological investigations. Foundations are always designed by a professional engineer in accordance with the requirements of SANS 10161. It is preferable to build a strip foundation that the timber frame will sit on (see

Figure 18). This was done using conventional concrete/clay bricks placed at 270-300mm apart and the cavity filled with concrete brick plinth.

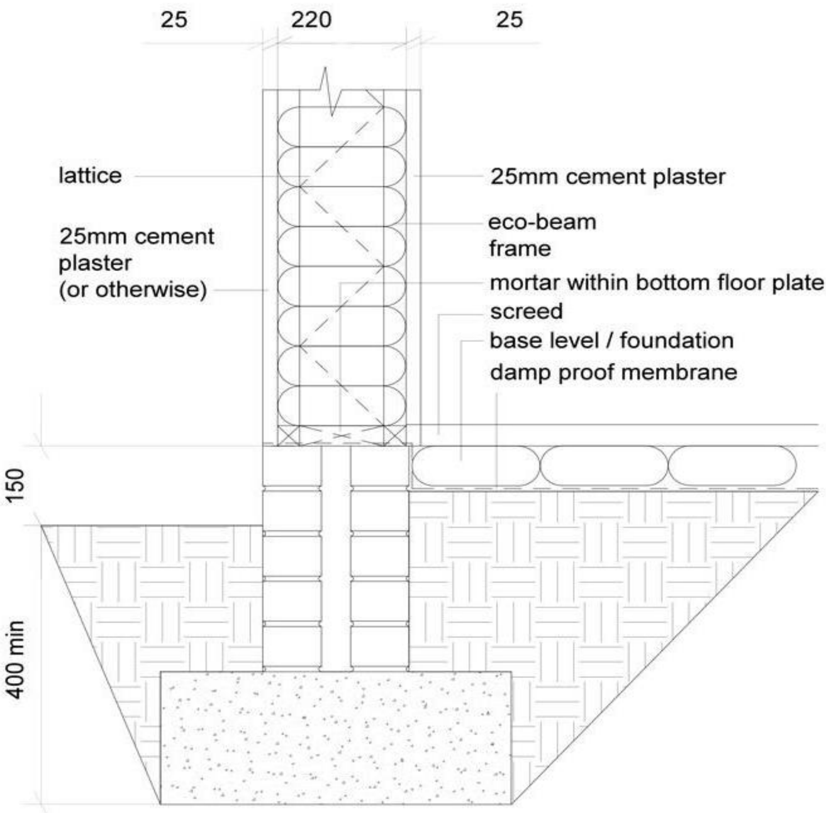

Figure 17: Typical section of a sandbag foundation.

Figure 18: Brick plinth

In some instances it might be possible to include a sandbag foundation, subject to engineer's requirements. This is normally done using a 1:20 mix of sand cement in the bags, two conventional bags wide to a depth to be agreed by the engineer.

5.2.5.2 Superstructure

⇒ Construction of Ecobeam (timber) frame walls

The erection of superstructure walls starts with the marking of the top and bottom Eco-beams at 900 mm intervals (or as stipulated by the architect). The vertical beams are nailed onto the top and bottom beams using two No. 100 mm ring-shank nails (or screws) one into each piece of the stud battens at the marked 900 mm intervals to form a frame. The length of the frame is as per the particular building project (see Figure 19).

(a) (b)

Figure 19: Sandbag Eco beam and Timber frame

Note: (a) marking of eco-beams; **(b)** timber frame

⇒ **Sandbagging**

a. Sand is natural soil with a clay content of less than 14% and free of any vegetable matter and generally has a bulk dry density of about 1500kg/m3. The maximum particle size is 20mm, with a grading envelope that allows easy filling, placing, and tamping. The sands must also be free of chlorides (e.g. sea sand) and other impurities which could cause the galvanised metal components to corrode. Ash and other industrial waste are not to be used as fill for bags.

Figure 20: Sandbagging

Note: (a)filling the bag; (b) mixing sand with water.

Sand is added to a ready-made tube / PVC pipe (cut to size) to ensure every sandbag has the same amount of sand added (see Figure 20). Sandbags filled with appropriate sand are packed between the framework in layers and patterns similar to masonry construction and tamped lightly (using a timber paddle).

b. The packing is done evenly across the frame which adds support to the frame. Precast concrete lintels, steel-reinforced concrete (SRC), or steel lintels are used over door and window openings with a minimum of 150mm.
c. It is advisable to adopt a 'stretcher bond' approach to packing, to increase stability as the wall is built (see Figure 21).

⇒ **Lintel installations (Doors, windows, and openings)**

Lintel installations are done in a conventional way, but instead of the lintel resting on a concrete block, it rests directly on the sandbags at the height of the head of the opening. The bearing will be 150mm or as specified by the engineer.

(a) (b)

Figure 21: Sandbagging 2

Note: (a) packing the bag; (b) stretcher bond

⇒ **Formwork for columns and beams**

a. When erecting the frame it is ensured that the corners are fixed to enable them to be filled with concrete. The 'shuttering' of the column can be achieved by using external cladding / temporary Shutterply to the exterior and the sandbags filled and placed against the corresponding walls internally.

b. The bags are taken up towards the top of the EcoBeam top plate, but a space (to be determined by the engineer but will be approximately 240mm deep) is left for the pouring of the concrete ring beam, which goes right around the perimeter of the structure.

c. When the concrete is sufficiently cured (and in the case where temporary shutterply is used) the shutterply can be removed ready for plastering. Bent metal mesh is used at the corners to ensure the plaster bonds sufficiently. This is because cementitious plaster reacts differently to timber than it does to concrete.

d. The structure stacked with sandbags is roofed using eco-beams or conventional trusses. Roof sheeting is supported using conventional purlins or battens. The trusses are fixed on the wall using hoop iron built six bags deep and wrapped around the trusses. In cases where a ring beam has been cast, this ring beam encases and secures the hoop iron to which the roof structure is secured. The spacing depends on the type of the roofing and it is always the responsibility of a professional engineer or approved competent person.

5.2.5.3 Services and Fittings module

⇒ **Electrical services and Plumbing services**

Electrical and plumbing elements are added to the structure before the bags are placed in the EcoBeam frame. Electrical sockets can be screwed to the EcoBeam frame and conduits added. The bags can then be packed around these elements and the conduit and bags can then be plastered.

⇒ **Installation of windows and doors**

a. There are two primary ways of fixing windows and doors. The first is by creating a Shutterply box to fit around the window or door, thickness of 220mm to fit into the EcoBeam frame. This is useful if it is desirable to fix the windows in place prior to a cladding system being installed.
b. In a scenario where the desire is for a conventional plaster finish, it is possible to create a hole for the window/door and affix it to the frame using proprietary clips as shown in Figure 22.

Figure 22: Window and door installation

5.2.5.4 Roofing

⇒ **Installing the roof on a sandbag structure**

a. Roofs can be installed in conventional ways, with conventional rafters and purlins subject to the project's requirements. It is imperative that the hoop iron (that binds the rafters to the roof plate) is installed prior to the pouring of the ring beam.

b. the hoop iron itself must be fixed to one of the vertical EcoBeams in the frame, to a distance of more than 300mm below the roof plate as shown in Figure 23.

Figure 23: Roofing

5.2.5.5 Cladding and plastering of sandbag walls

a. Once the sandbags are appropriately packed, fibre-reinforced plaster is used ,and/or an anti-alkali fiberglass mesh/galvanized chicken wire is nailed onto the vertical beams over the entire building prior to plastering as shown in Figure 24.

b. The structure packed with sandbags between the framework is wetted before plastering. Plaster is conventional cement-sand plaster and at least 25 mm thick minimum. Standard 32.5 N Portland cement is used in a mixing ratio of between 1:4 and 1:6 (cement: sand). Plaster sand to conform to SANS1090 with a clay content of less than 7.5%. Also, 600g of Fibsol fibre may be added to each cubic metre of plaster to prevent plaster cracks.

Figure 24: Wall cladding

(a) (b)

Figure 25: Wall plastering

Note: (a) wall plastering (b) finished plaster ready for priming

c. Sandbag technology is extremely adaptable, to the extent that it can be used in building a home incrementally (bit by bit). The EcoBeams can be erected and a cladding system applied straight away to provide a sealed box. This enables the owner/builder to continue adding to the building while living in it.
d. Zinc, timber, and other systems can also be used as external cladding. During construction the cladding is

used to finish the sandbag wall and minimize the amount of plaster used in the process.

e. Internally plaster can be used, but also timber or other materials are applied straight onto the sandbag walls.

5.2.5.6 Painting, skirtings, cornices

Internal finishes are achieved in conventional ways (see Figure 26 for different types of finishes).

⇒ Service fittings and connections

Service fittings can be situated within the plastered wall/cladding or surface mounted, as per standard details.

⇒ Flooring

In certain instances, a ground floor slab consisting of cement stabilised bags with a structural topping/screed may be used. These would rest on the damp proof membrane which sits on the compacted earth/sand. These methods are always the responsibility of a professional registered engineer.

(a)

(b)

(c)

(d)

Figure 26: Wall and floor finishing
Note: (a) painting of sandbag wall; (b, c) cladding of sandbag wall with zinc; (d) flooring

⇒ **Insulation / Ceilings**

Insulation and ceilings are achieved in conventional ways, subject to the project's requirements.

6.0 References

1. Adabre M.A., Albert P.C, Amos D., Robert O. Rotimi A. and Theophilus A. 2020. Critical barriers to

sustainability attainment in affordable housing: International construction professionals' perspective. Journal of Cleaner Production 253 119995

2. Adabre M.A. and Albert P.C Critical success factors (CSFs) for sustainable, affordable housing. Building and Environment 156 (2019) 203–214
3. Aigbavboa, C., & Thwala, W. (2018). Prediction of Residential Satisfaction in South African Low-Income Housing: Role of Beneficiaries. Journal of Architectural Engineering, 24(1), 05017011. doi: 10.1061/(asce)ae.1943-5568.0000282
4. Alaazi, D. A., & Aganah, G. A. 2020. Understanding the slum–health conundrum in sub-Saharan Africa: a proposal for a rights-based approach to health promotion in slums. Global health promotion, 27(3), 65-72.
5. Ben-Alon, L., Loftness, V., Harries, K. A., Hameen, E. C. & Bridges, M. 2020. Integrating earthen building materials and methods into mainstream construction. Journal of Green Building, 15(1), 87-106.
6. Botes, A. W. (2013). A feasibility study of utilising shipping containers to address the housing backlog in South Africa. Doctoral dissertation, University of Stellenbosch.
7. Calburn, S. 2010. AZA 2010 Pavilion. https://sarahcalburn.co.za/portfolio/aza-2010-pavilion/ Retrieved: 13 September 2021

8. Cataldo-Born, M., Araya-Letelier, G. & Pabón, C. 2016. Obstacles and motivations for earthbag social housing in Chile: energy, environment, economic and codes implications. Revista de la Construcción. Journal of Construction, 15(3): 17-26.
9. City of Cape Town. (2018). Municipal Spatial Development Framework. https://resource.capetown.gov.za/documentcentre/Documents/City%20strategies%2C%20plans%20and%20frameworks/CT_Metropolitan_Spatial_Development_Framework.pdf (Accessed September 2021).
10. Dabaieh, M., & Said, R. (2013). Affordable, sustainable earthbag housing; achieving indoor thermal comfort in low-cost housing in Egypt. In SB13, Advancing the Green Agenda; Technology, Practices and Policies. Advancing the Green Agenda; Technology, Practices and Policies. SB13 8-10 December 2013, Dubai, UAE.
11. De Villiers, W. & Boshoff, W. P. 2012. The development of a decision-making model to determine the appropriateness of alternative building technologies for application in the social housing industry.
12. Dlamini, T. U. 2020. The feasibility of wood-plastic composites as building material for RDP houses in South Africa. Ph D dissertation, Stellenbosch University.

13. Dosumu, O. & Aigbavboa, C. 2019. An investigation of the benefits and challenges of adopting Alternative Building Materials (ABM) in the construction industry. In Innovative Production and Construction: Transforming construction through emerging technologies. 261-277.
14. El-Kabbany, M. F. 2013. Alternative Building Materials and Components for Affordable Housing in Egypt: Towards improved competitiveness of modern earth construction. Degree of Master of Science in Integrated Urbanism and Sustainable Design, Ain-Shams University, University of Stuttgart.[Online] Available: iusd. asu. edu. eg/wp-content/uploads/2015/11/1stInt_El-Kabbani. (pdf) Accessed 20 June 2020.
15. Friedman, R., Rosen, G., 2018. The challenge of conceptualising affordable housing: definitions and their underlying agendas in Israel. Hous. Stud. 1e23
16. Geiger, O. & Zemskova, K. 2015. Earthbag technology–simple, safe, and sustainable. Nepal Engineers Association Technical Journal. Special Issue on Gorkha Earthquake. 43:78-90.
17. Golubchikov. O. and Badyina. A. Sustainable Housing for Sustainable Cities: A Policy Framework for Developing Countries, (2012).
18. Grady, B., Muzila, D., O’Neill, K., Tanner, A., Belz, M., Tshiguvho, T. & Gumede, D. 2019. Alternative Building Technologies for Low-Income Housing in

Cape Town, South Africa. Doctoral dissertation, Ph. D. Thesis. Worcester Polytechnic Institute, Worcester, MA, USA.

19. Hadjri, K., Osmani, M., Baiche, B., & Chifunda, C. 2007, September. Attitudes towards earth building for Zambian housing provision. In Proceedings of the Institution of Civil EngineersEngineering Sustainability. 160(3): 141-149. Thomas Telford Ltd.
20. Hunter, K. & Kiffmeyer, D. 2004. Earthbag building: The tools, tricks, and techniques. Volume 8. New Society Publishers.
21. Kulshreshtha, Y., Mota, N. J., Jagadish, K. S., Bredenoord, J., Vardon, P. J., van Loosdrecht, M. C. & Jonkers, H. M. 2020. The potential and current status of earthen material for low-cost housing in rural India. Construction and Building Materials. 247, 118615.
22. Lyamuya, P. & Alam, K. 2013. Earth Construction in Botswana: Reviving and Improving the Tradition. CAA DHAKA 20th General Assembly and Conference. 2 Macêdo dos Santos, D. & Beirão, J. N. D. C. 2017. Generative tool to support architectural design decision of earthbag building domes.
23. Man, S. S., Chan, A. H., & Wong, H. M. (2017). Risk-taking behaviors of Hong Kong construction workers– A thematic study. Safety Science, 98, 25-36.

24. McIntosh, A. A. (2019). Case Study Investigations and Design-Build Proposal near Gisenyi, Rwanda. UF Journal of Undergraduate Research, 20(3).
25. Moghayedi, A.; Awuzie, B.; Omotayo, T.; Le Jeune, K.; Massyn, M.; Ekpo, C.O.; Braune, M.; Byron, P. A Critical Success Factor Framework for Implementing Sustainable Innovative and Affordable Housing: A Systematic Review and Bibliometric Analysis. Buildings 2021, 11, 317. https://doi.org/10.3390/buildings11080317
26. Morgan, D.L., 1997. Focus Groups as Qualitative Research. SAGE Publications, Inc, Thousand Oaks, California.
27. Nadal, A., Cerón-Palma, I., García-Gómez, C., Pérez-Sánchez, M., Rodríguez-Labajos, B., Cuerva, E., & Rieradevall, J. (2018). Social perception of urban agriculture in Latin-America. A case study in Mexican social housing. Land Use Policy, 76, 719-734.
28. National Home Builder's Registration Council. 2020. Promoting Innovative Building Technologies. https://www.nhbrc.org.za/wp-content/uploads/2020/10/Promoting-IBTs-for-the-NHBRCWebsite. Pdf Retrieved 10 September 2021.
29. National Summit on Housing Affordable, 2006. Achieving a national affordable housing agreement: background paper 2: key terminology and indicators. In: National summit on housing affordability

30. Ncube, N. R. 2017. Investigating the feasibility of the use of Moladi construction technology to assist in-situ upgrading in Informal settlements within the eThekwini Metropolitan area. Doctoral dissertation. University of KwaZulu Natal.
31. Pollack, C.E., Griffin, B.A., Lynch, J., 2010. Housing affordability and health among homeowners and renters. American journal of preventive medicine 39 (6), 515e521.
32. Pullen, S., Arman, M., Zillante, G., Zuo, J., Chileshe, N., Wilson, L., 2010. Developing an assessment framework for affordable and sustainable housing. Australas. J. Constr. Econ. Build. 10 (1/2), 60.
33. Reddy, B. V. and Mani, M. (2007). Preface: Proceedings, International Symposium on Earthen Structures, Indian Institute of Science, Bangalore, 22-24 August. Interline Publishing, India.
34. Rincón, L., Carrobé, A., Martorell, I. & Medrano, M. 2019. Improving thermal comfort of earthen dwellings in sub-Saharan Africa with passive design. Journal of Building Engineering. 24: 100732.
35. Salzer, C., Wallbaum, H., Lopez, L. F. & Kouyoumji, J. L. 2016. Sustainability of social housing in Asia: a holistic multi-perspective development process for bamboo-based construction in the Philippines. Sustainability. 8(2): 151.
36. Santos, D. M. & Beirão, J. N. D. C. 2016. Data collection and constructive classification of

superadobe buildings. Ciência e Sustentabilidade. 2(2): 208-226.

37. Schmidt, S., Muller, P., Vollmer, B., Laubscher, D.J., Steynberg, D.J., van der Merwe, D., Pienaar, M., Pienaar, M. et al. 2013. Architective Building Construction Standards for South Africa. In S. Schmidt, B. Vollmer, F. le Roux, & J. le Roux (eds.). Architective Building Construction Standards for South Africa. 260–265. Johannesburg, South Africa: Architective Publications.
38. Shaker, A., Medhat, H., Abou-elgheit, M., Nassar, M., Mahmoud, Y., Hamza, A. S. and Abou-Zeid, M. 2017. A proposed sandbag housing unit for poor and disadvantaged Areas. Conference proceeding: Leadership in Sustainable Infrastructure. Vancouver, Canada. May 31 – June 3.
39. South Africa Housing and infrastructure Fund. 2020. Alternative Building Technologies. November 2020. Pdf Retrieved 10 September 2021.
40. Sullivan, E., Ward, P.M., 2012. Sustainable housing applications and policies for low-income self-build and housing rehab. Habitat Int. 36 (2), 312e323.
41. Survant, T. 2014. Support GA Collaborative's Earthbag Projects in Rwanda: Building Community through Creative Construction. ArchDaily. 9 April. Accessed 13 September 2021. https://www.archdaily.com/493914/support-ga-collaborative-s-earthbag-projects-in-rwandabuilding-

community-through-creative-construction> ISSN 0719-8884.

42. Tshivhasa, T. & Mbanga, S. 2018. Pointing innovative building technologies path through learnt experiences for sustainable human settlements development: a case study of Thembelihle Manyano project in the Eastern Cape Province. Out-Of-The Box 2018 Human Settlements. 128.
43. Ugochukwu, I. B. & Chioma, M. I. B. 2015. Local building materials: an affordable strategy for housing the urban poor in Nigeria. Procedia Engineering. 118:. 42-49.
44. Zami, M. S. & Lee, A. 2011. Inhibitors of adopting stabilised earth construction to address the urban low-cost housing crisis: An understanding by construction professionals. Journal of Building Appraisal. 6(3):227-240.