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Improving sustainability of affordable housing using innovative technologies: Case study of SIAH-Livable

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ABSTRACT

Rapid urbanization presents a major challenge in achieving affordable and sustainable housing. In the face of the problem, rapid urbanisation represents, there is room for innovation. Advancements in sustainable design methods, new materials, and innovative building technologies offer potential solutions for developing sustainable, innovative, and affordable housing (SIAH). This study investigates various sustainable design techniques, materials, and technologies suitable for designing SIAH in the South African climate in concordance with local building codes and regulations. The study compares the building performance of SIAH-Livable, as assessed by energy embodied, energy demand, and water usage, with that of conventional low-cost housing using the EDGE Buildings App. The results validate that SIAH-Livable building performance is significantly less water and energy, reducing consumption by 55.17% and 21.06%, respectively. Additionally, SIAH-Livable exhibits a noTable 66.9% reduction in embodied energy levels while remaining within the construction cost range defined by the South African government for low-cost housing. Furthermore, the analysis confirms that appropriate design techniques, new materials, and technologies not only enhance the sustainability of the house but also improve its affordability by reducing lifecycle costs. The study concludes that sustainable design techniques, including passive design, the use of recycled and local materials, and socio-technical innovations, are effective means of enhancing the sustainability and affordability of housing, contributing to the development of SIAH. Importantly, this research establishes the association between sustainability and affordability in South African housing design, offering insights that can be adapted and applied to other African countries.

Introduction

Global demand for affordable housing has increased due to rapid urbanization, economic challenges, high unemployment rates, poverty, and climate change-related natural disasters. Anthropogenic factors have exasperated the rate of environmental disasters like flooding, rapid increases in human population and political unrest. Because of these factors, the need for housing and safety has been difficult to meet in South Africa [1]. South Africa is a developing country with a growing housing backlog for low-cost housing. This backlog has been on the increase in the last few years, highlighting a need to find better housing solutions. The term 'affordability' in

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terms of the proposed SIAH design proposal speaks directly to the need for affordable solutions that address a backlog in low-to-middle-income groups within the South African context.

In South Africa, the provision of low-cost housing has been fraught with low-quality workmanship and sub-optimal construction methods. Low-cost housing also struggles with high levels of energy wastage, inefficient water use and high carbon footprints. Unsustainable practice in housing delivery is aggravated by a lack of passive design principles and the use of proper materials and techniques [2,3]. Therefore, the gap in South Africa's low-cost housing delivery lies in its need to adopt innovation that enhances construction speed and quality, ensures build sustainability and mitigates wastage. The SIAH-Livable design responds to this need by first incorporating the South African climate zones and the location of the house concept. The proposal then sought to achieve optimum environmental sustainability by maximising passive design principles and considering water and energy efficiencies. The proposed design then looked at the production of on-site energy, food and on-site water reclamation. The SIAH-Livable house needed to be designed as efficiently as possible. The project aimed to achieve a minimum energy intensity unit score (EUis) of 50KWh/m2/year with the remaining electricity demand generated on-site [3]. The intention behind implementing a sustainable design lay in the identification of a need to shift from pure economics and affordability to the enrichment of social and environmental health, improving the well-being of occupants as well as the community.

The current study is a pioneering effort that addresses a significant gap in the literature by exploring the conceptual understanding of sustainability in South Africa and its practical application to affordable housing. By specifically focusing on this intersection, the study aims to provide valuable insights into the relationship between sustainability and affordability in housing design. What sets this research apart is its comprehensive examination of these interconnected elements, offering a holistic perspective that surpasses a singular emphasis on either sustainability or affordability.

The research's novelty lies in its integration of the entire cycle of sustainable design, including the selection of new materials, advanced methods, and innovative techniques, within the context of actual affordable housing in South Africa. By taking into account the diverse local contexts and constraints, the study aims to advance knowledge not only about affordable housing in South Africa but also about housing across the entire African continent. Additionally, this study seeks to investigate the impact of socio-technical innovations on the performance and cost-effectiveness of affordable housing.

This paper is structured as follows: Section 2 provides an overview of the literature on the sustainability of affordable housing and the role of innovative technologies in engendering the sustainability of affordable housing, Section 3 presents the process of designing SIAH-Livable and methods utilised for quantifying the sustainability of the house proposed, Section 4 presents design details and discusses the results and finally Section 5 offers a few pertinent conclusions.

Literature review

In South Africa, sustainability and affordability are often seen as separate matters in the rollout of housing and thus targeted from these two different angles [1]. Environmental sustainability in South Africa and the African context is approached differently, primarily due to the country's developing nature. Achieving a balance between cost-effective solutions and long-term infrastructure is crucial for managing waste, adopting new technology, ensuring sustainable energy provision, preserving water quality and keeping water sources healthy. To design affordable housing that meets regional needs in South Africa, it is imperative to research investigates sustainability requirements, affordability factors, innovation opportunities, and housing development demands specific to each region.

Sustainability of affordable housing

Based on the context of the global economies recovering from pandemic lockdowns, the drive to respond to climate change and the need for affordable and sustainable housing has not been more prevalent. Anthropogenic factors, environmental disasters like flooding, increases in the human population, and political unrest have elevated the need for housing. In addition to the factors listed here, the issue of safety has been a difficult factor to meet in South Africa specifically [1]. This is because South Africa is facing a housing backlog that has been on the increase in the last few years [4]. The provided housing catered to households with a maximum combined income of R3500 or less. However, banks in South Africa only award bonds to households earning a minimum of R15000 or more. This has caused affordable housing for the low-middle income bracket to be missing in the housing market and has been called the "Gap" market [5]. Thus, there is a great need to supply affordable housing for the low to middle-income household sector in South Africa. The provision of affordable housing aims to break the cycle of poverty by granting people access to increased employment opportunities, as job security remains a pressing concern in societies worldwide [1].

Sustainability is understood as the definition of catering to the socio-political well-being of people and communities, viable economical applications, and environmental custodianship of natural resources [6]. Sustainability has been considered an important aspect of development within South Africa. This emphasis on sustainability was officially established in the governmental white paper publication on national climate change (2010) outlining the strategy for the countries' response to climate change. Despite this declaration, the implementation of sustainable construction principles has not been advanced in the built environment on a large scale. This lack of sustainable construction principles in implementation is largely due to cost-based drawbacks [7].

The application of sustainable construction principles in South Africa is often engaged on a voluntary basis with the use of the Green Star (or equivalent) building rating system. The construction industry in the built environment plays one of the most significant roles in climate change with the development of projects minimising natural land, using resources as well as producing building waste that contributes to landfills [1,8]. This puts an emphasis on the urgent need to fulfil the housing demand in as sustainable a manner as possible. This needs to be achieved while not compromising on quality, rate of output and the cost of each project. The focus, to date,

within the development of the housing domain has been significantly economical. This proportionately equates to a lack of embedded elemental dynamics in sustainability. The lack of sustainable systems in construction is a growing concern, particularly in regard to social, environmental and innovative components [9].

Environmental sustainability in housing

Moghayedi et al. [7] explain that sustainable housing refers to the use of sustainable building methods, sustainable building technologies and components, and the promotion of greener principles in living a sustainable life. Since the 1990s, there is a global consensus that the building and construction industry impacts the natural environment in a very unsustainable manner [10,11]. This manifests in the building and construction industry's heavy use of natural resources, the clearing of land and symbiotic environments, the extreme consumption of energy and water, the careless release of pollution into arable soil and natural water bodies and the production of non-biodegradable waste that fills up landfills. The building and construction industry also participates in the development of the heat island effect via urban sprawl and hard surface ground cover contributing to global warming [11]. The minimisation of CO2 emissions, along with the generation of renewable energy and water preservation with a focus on efficient use and the conservative use of natural resources in order to do little to no harm, are some of the strategies employed in environmentally sustainable housing to combat the construction industries negative imprint on the environment.

Social sustainability of housing

The provision of adequate shelter is not only a fundamental human right but also crucial for overall human well-being [1]. However, it is essential to recognize that the social dimension of sustainability extends beyond mere housing provision and encompasses the intricate relationship between occupants, society, and the built environment in specific locations [12]. Sustainable housing should be designed to meet the needs of its residents and foster a sense of community and belonging. Additionally, it should be affordable to ensure universal access.

Social sustainability in housing encompasses various aspects that contribute to residents' well-being and quality of life. These include accessible transportation options, the influence of the built environment on occupants' lifestyles, the creation of safe and secure environments for families and communities, and the promotion of general well-being [7]. It is crucial to consider housing as more than just shelter by incorporating factors such as thermal and spatial comfort, aesthetically pleasing design, and affordability of rates and taxes, which are integral to occupants' overall well-being and habitability.

Promoting social sustainability in housing can be achieved through various strategies. Designing mixed-use housing, for instance, fosters a diverse and vibrant urban environment where individuals can live, work, and engage in various activities in close proximity, thus promoting community integration and reducing social isolation [13]. Proximity to public transportation, schools, and amenities is another important factor in creating socially sustainable housing, as it enhances accessibility and facilitates residents' access to necessary resources [14]. Furthermore, ensuring that sustainable housing is affordable is critical. Utilizing innovative sustainable housing design, materials, and methods can help reduce construction costs and decrease long-term housing expenses, thus enhancing affordability [9].

To achieve social sustainability in affordable housing, the involvement of stakeholders from diverse backgrounds, including residents, community organizations, housing providers, and local government, is crucial. Engaging in dialogue, conducting community needs assessments, and implementing targeted policies and programs can ensure that affordable housing not only meets residents' basic needs but also enhances their social well-being, fosters a sense of belonging, and promotes a strong sense of community.

Economic sustainability in housing

Economical sustainability refers to the affordability of shelter provision, access to economic opportunities within the social environment of a community and the ability to service the economic requirements of provided housing. However, the consideration and combination of sustainability and affordability have been difficult to achieve in South Africa due to the spatial demands of households and the initial layout cost of approved sustainable building materials [15]. The drive for a physically safe shelter (manifested as a house), access to the housing market, and the affordability of the cost post occupancy of a house cannot be excluded in the provision and design of sustainable housing. Affordable housing is based on income and the capability of the owner or potential owner to provide for their dwelling needs.

Moghayedi et al. [7] explain that the affordability of housing refers to the occupants being able to carry the cost of the dwelling without negative consequences on their lifestyle and social impact on the community. The term affordability is described as a broad term and is difficult to define, for it may be different in each sector of society [7]. Affordability is therefore based on each household's financial budget, approximately 30% of the total household income, in order for other living costs to be catered for [16–18]. Neighborhoods that are well-managed and well-planned can redefine the value of a property introducing the social, environmental and economic factors that will enhance the neighborhoods' community members resulting in an improved quality of life [19].

The role of socio-technical innovations on the sustainability of affordable housing

Conventional building materials and construction methods, such as fired clay brick, cementitious products, and corrugated iron roof sheeting, are widely employed in low-cost housing. The term 'Innovative;' refers to technologies that use building technology in a way that expands beyond the conventional way of building in order to enhance the thermal and ecological performance of the house for the occupant's comfort. For example, the potable water supply provided by the municipalities is under pressure at a cost versus localised innovative technology of filtered stormwater to supply potable water to a dwelling at no running cost. The demand for

affordable housing ([20,21]; Butcher) leads to the immediate demand and consumption of suitable building technology (Muazu et al. [1]). This causes the housing sector to contribute to a large amount of building material that contributes to CO2 emissions and high embodied energy material consumption globally (Adabre et al.; Li et al. [1]). Therefore, the need for innovative building methods that are easy to install, cost-effective, done at a quick pace and support a regenerative agenda in sustainable output are to be fulfilled now more than ever. The built environment's construction technology needs to adapt from conventional methods to more sustainable ways of manufacturing and installing to combat current climate change and environmental disaster problems, for example, excessive plastic and waste dumping on landfills with no fast waste management plan like biodegradable products etc. [9,22]. This is also exacerbated by cheaper building options that make a housing development more viable and faster to install but are not necessarily suitable for the community or the sustainable criteria of a project.

Moghayedi et al. [7] explain in their paper that the provision of sustainable and affordable housing, focusing on technology and execution, is based on the interest of role players like developers, investors and contractors to innovate in the design and housing delivery. Cost factors are a major driver of innovation in sustainable and affordable housing in South Africa. Despite government policies on sustainability and climate change mitigation, the public sector has largely been responsible for driving this agenda. The private sector has not responded in this sense, and therefore the housing provision has been lacking in innovation for the low-cost affordable housing market [7]. Moreover, they explain that the decline in housing delivery also drives the demand to be higher, and thus the cost of houses increases subsequently globally. The lack of sustainability of conventional building methods is high in ecological resource degradation and land erosion, allowing for innovative and natural building methods to be incorporated into the construction of affordable housing [23].

The preponderance of underperforming housing projects from the sustainability prism has sought to perpetuate the view that the challenge of providing adequate, affordable housing cannot be solved by the continued deployment of traditional methods, outdated techniques and conventional materials. Moghayedi et al. [9] proved that the utilization of innovation can improve the efficiency and affordability of housing projects' development. Furthermore, they proved innovation is an adequate mechanism for enhancing the development and sustainability of housing, which impacts significantly on people's lives, health, dignity, safety, and their neighbourhoods.

Methodology

The study aims to quantify the effectiveness of the application of passive design principles, innovative building materials and innovative building methods on the sustainability of affordable housing. To this purpose, parametric energy, water and cost dynamics analyses were performed and compared to a typical conventional low-cost house in South Africa to evaluate the effectiveness of passive design and innovations on sustainability and affordability of South African houses.

Therefore, the study adopted a quantitative approach conducted in the following four steps:

Step 1: Design the concept of SIAH-Livable and its expansion phases based on passive design principles.

Step 2: Select the most appropriate innovative building materials and methods available in the South African market.

Step 3: Simulate the energy embodied, water and energy demand of the SIAH-Livable house and compare them to the building

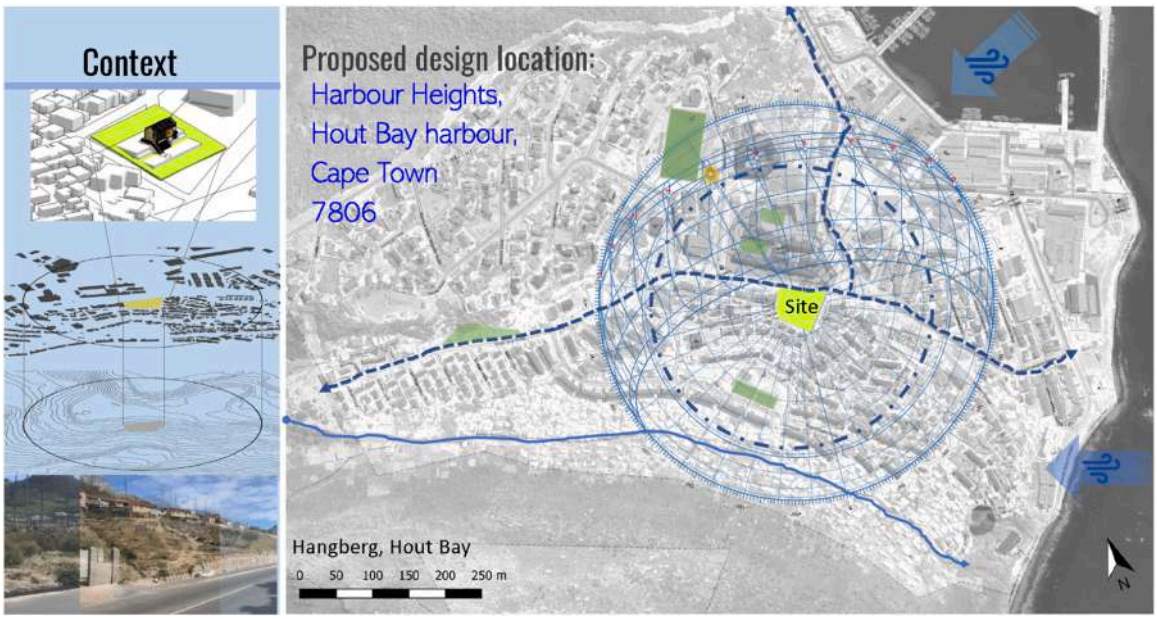

Fig. 1. SIAH-Livable proposed location.
Source Phiri and Bosa. 2021.

performance of a conventional house.

Step 4: Estimate the cost of building construction.

The SIAH-Livable was designed for temperate coastal climate zone environmental conditions in South Africa (dry and warm summer) with 16–26 °C in summer and 7–16 °C in winter. The project's location in Hout Bay Harbour Heights in Cape Town, see image below, shows the environmental context of the site, as shown in Fig. 1.

The SIAH-Livable was designed to serve a family of four, containing two bedrooms, a toilet and bathroom and cooking and living areas in a total 50 Square metre floor plan as a standard low-cost housing scheme defined by South African human settlement. The design of the SIAH-Livable house was conceptually developed in sketch-up and then developed in detail in Autodesk Revit. GIS and Koppen Geiger read were used to simulate the local climatical condition, with the city of Cape Town Electrical and hydrological data aiding estimates and enhancing the passive design of the house. Finally, the EDGE package, a credential simulation programme by the world bank, was utilised to quantify the amount of embodied material energy and compared the energy and water demands of SIAH-Livable to a common conventional low-cost house in South Africa. Finally, a bill of quantities for building the designed house was generated, and the total building cost was estimated using the South African 2021 price list.

The SIAH-Livable design

The Sustainable Innovative Affordable House (SIAH) was designed with a goal. The design goal was the integration of innovative, emerging technologies into a housing scheme. While the initial design focuses on a single dwelling referred to as the 'SIAH-Livable House', the project encompasses sustainable solutions throughout the entire lifespan of the dwelling, from inception to demolition. The SIAH-Livable design incorporates the concept of a Livable Neighbourhood urban design (Smith, 2022), an idea that is context specific to South African human settlement needs. The design is thought of as an expansive sustainable project that may be introduced into neighbourhoods at various phases of expansion. The SIAH-Livable House design offers solutions that conform to the current dynamic in the African Socio-Economic plane. The design is based on adjustable modular elements that maintain critical response while improving quality of life. The building design introduces an upgrade system in a simple package, ready to construct, live in, and grow, as illustrated in Fig. 2. The reimagining of technocentric green design into "SIAH-Livable" begins with the design. The building itself will offer lessons to help awareness and promote a sustainable local culture.

By designing SIAH-Livable with adaptable spaces and expandable layouts, homeowners have the ability to accommodate changing needs and circumstances over time. This flexibility allows for adjustments to the living environment, such as accommodating a growing family, providing space for home-based work or business activities, or creating separate living areas for multi-generational

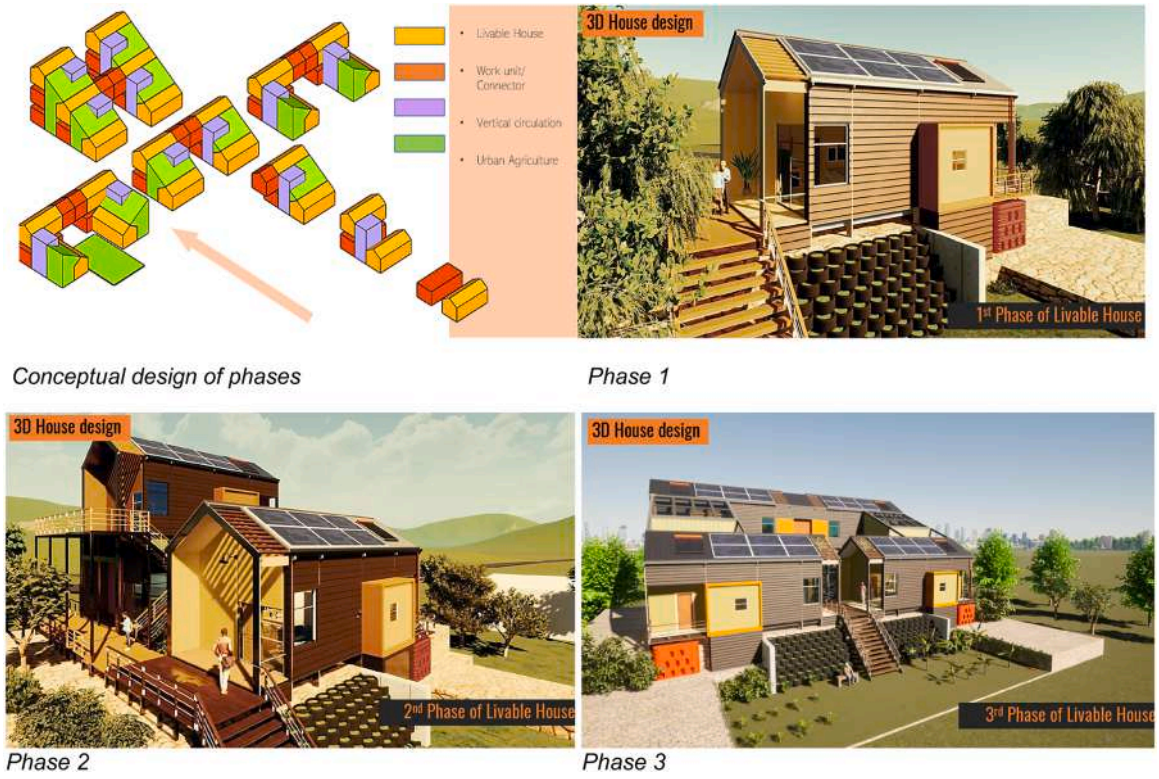

Fig. 2. SIAH-Livable phases.
Source Phiri and Bosa. 2021.

households. The ability to modify and expand the house reduces the need for relocation, fostering a sense of stability and continuity within the local community. Moreover, the high flexibility of SIAH-Livable design promotes inclusivity by accommodating individuals with diverse physical abilities and supporting ageing in place. By offering residents the opportunity to adapt their homes to suit their evolving needs, expandable and flexible houses contribute to social sustainability by fostering long-term community engagement, promoting social cohesion, and providing a supportive environment for residents to thrive. The SIAH-Livable House is designed for a family of four (parents with two children). The design aims to include innovative aspects that provide alternative solutions to the needs of the occupants, augmenting efficiency, minimising waste of materials and maximising spatial utility.

The project concept of regenerative framework

To achieve true affordability, the SIAH-Livable considers the full lifecycle as an opportunity to achieve sustainability. The project's aim is to be cheaper to source, assemble and operate in multiple stages of construction, occupation, maintenance, and re-use. Based on the figure of the regenerative framework (See Fig. 2), the three levels of design intervention are considered as means by which a South African housing program can reduce the impact on the environment and reduce the quantity of materials used at various phases of building construction. This optimises the regenerative factors present in reuse and recycles strategies that take the lifespan and longevity of the SIAH-Livable House into account. The development phase, based on the implementation of the design concept, emphasises community liaison and engagement with stakeholders and the design team [24]. The aim is to produce tailor-made plans for the multiple interests, ideas and perspectives within the community. Reflecting on community members and their way of living as shown in Fig. 3. The project aims to be drawn up for council submission, once approved the SIAH-Livable House will be constructed based on a prefabricated kit (See Fig. 3). The dwelling(s) is proposed to be assembled in an assembly workshop that will enhance localised job creation. In a scaled-up implementation model, a prospective homeowner would ideally sign a contract for subsidised loans towards their ownership of the SIAH-Livable House. For such a model to work, engagement with stakeholders would need to be enacted. Phiri [24] formulated the SIAH-Livable design to follow a series of upgrades that incorporate the SIAH-Livable unit(s), the work unit(s), vertical circulation cores and localised urban agriculture. The installation will need to be North facing with space marked

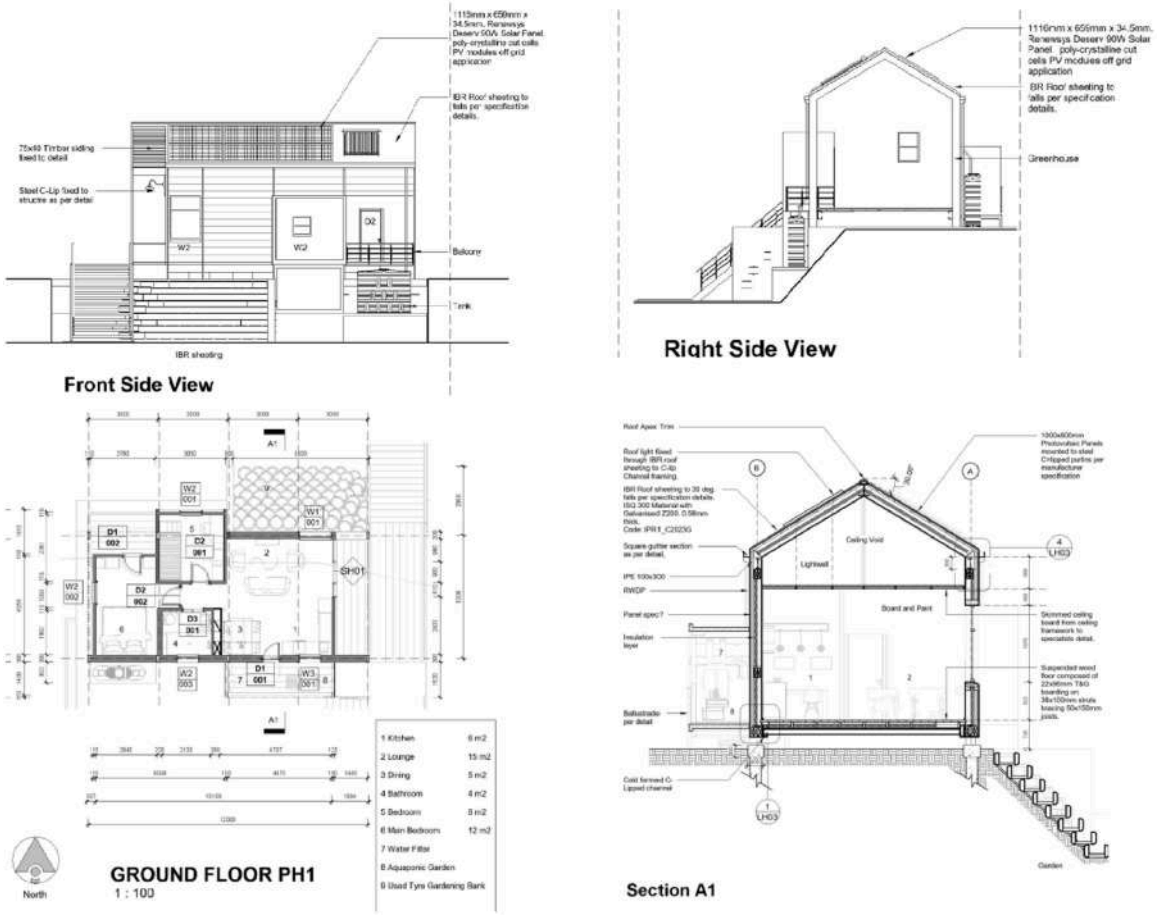

Fig. 3. Design drawing details and specification.
Source Phiri and Bosa. 2021.

out for upwards development. The upgrade phases are inspired by the backyarder culture, hinting at the general desire for this type of model. As the homeowner develops, so too does their ability to provide housing as a landowner.

The design approach

With the goal of the design approach based on the proposed developments of neighborhoods the ideal is that the design transcends the conventional understanding of bare minimum living solutions. The aim is to allow affordable homes to be able to also sustainable, in essence, in order to ensure net-positive food and water amenities. The amenities are based on the homeowner's ability to maintain and afford the initially implemented systems. In order to maximise the application and implementation of the proposed amenities, passive heating and cooling systems, renewable systems, alternative building materials, hydroponics, and aquaponics are to be implemented at varying architectural scales [24].

Passive heating strategies in the SIAH-Livable design consider the need for warmth during cool days (mostly winter). The winter conditions allow for a lower sun path to introduce direct sunlight into key living spaces, as shown in Fig. 4. This is ideal for providing an affordable solution by using natural heating. It is important to hold this heat in the building by providing sufficient insulation where the heat may escape. Hence the walls, roof and floors all possess sustainably produced paper-based insulation. The cooling of the dwellings considers the need for a reduction of heat during the hotter days of summer. In Cape Towns' summer season, the sun angle is high on the horizon. The SIAH-Livable House reduces excessive direct solar access into the building by the use of small windows and marginal overhangs. Windows are positioned to allow cross ventilation through the whole house when fully opened. Heat can is also allowed to escape through vented windows through the roof on the south side of the building (See Fig. 4). The building takes advantage of rising air systems and high-level openings to enable night flush ventilation of heat accumulated during the warmer half of the day [24].

The general sun path allows for natural light and thermal comfort to be achieved. In the morning (9 am), the lounge area receives a fairly large amount of direct sunlight. This allows internal temperatures to climatise. At midday, the lounge area receives much less direct natural light. At this point temperature has risen, and passive internal cooling begins. In the Southern hemisphere, at 3 pm, the sun holds the hottest temperature due to ambient heat accumulation. At this point, the lounge is completely in the shade and can begin to release the day's heat steadily. The water strategy also factors in the SIAH-Livable Houses' passive building systems [24]. Due to the intended location of the project being in Hout Bay, Cape Town, the need to preserve and conserve water is an essential component of ecological sustainability. Thus, the SIAH-Livable House is intended to be used in environments where stormwater proves itself to be a problem due to either drought or regional and seasonal flooding exacerbated by climatic detractors like the heat island effect. By standing proud of the ground the dwelling reduces the chance of flooding. The SIAH-Livable House also collects all the rainwater from the roof and guides this water to storage tanks for use in and around the dwelling. Considering all these natural parameters in the design of a house significantly contributes to the enhancement of social sustainability in housing development. The prioritisation of energy efficiency, thermal comfort, and indoor air quality works hand in hand with the provision of consistent temperatures, improved air quality, and reduced noise levels, The SIAH-Livable House promotes better physical and mental well-being by employing passive solutions, which positively impact the overall quality of life for residents.

The structure and technical details.

Design details

Details A and B to showcase the technical details of the insulative EPS system used in conjunction with the timber cladding and structural frame, as details illustrated in Fig. 5.

Sustainable infrastructure: energy and water usage

In the face of resource and water scarcity, water management and energy generation within the SIAH-Livable house were reimagined, as shown in Fig. 6. The energies are to be conserved but also returned or processed on-site. The development of sustainable

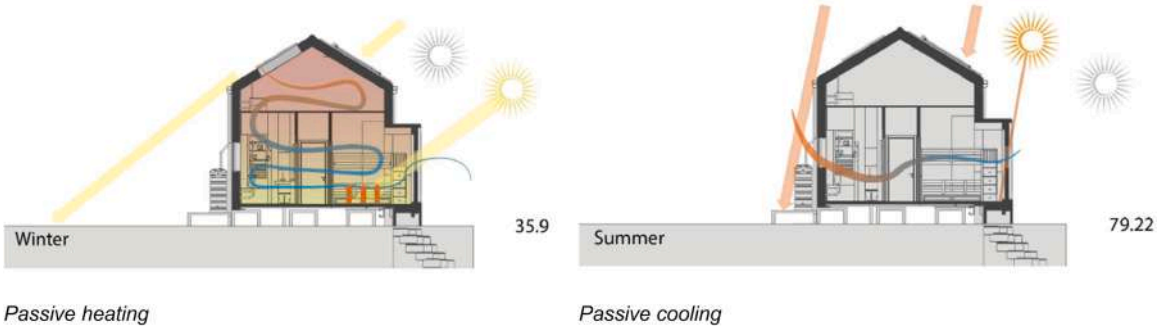

Fig. 4. The passive heating and cooling systems.
Source Phiri and Bosa. 2021.

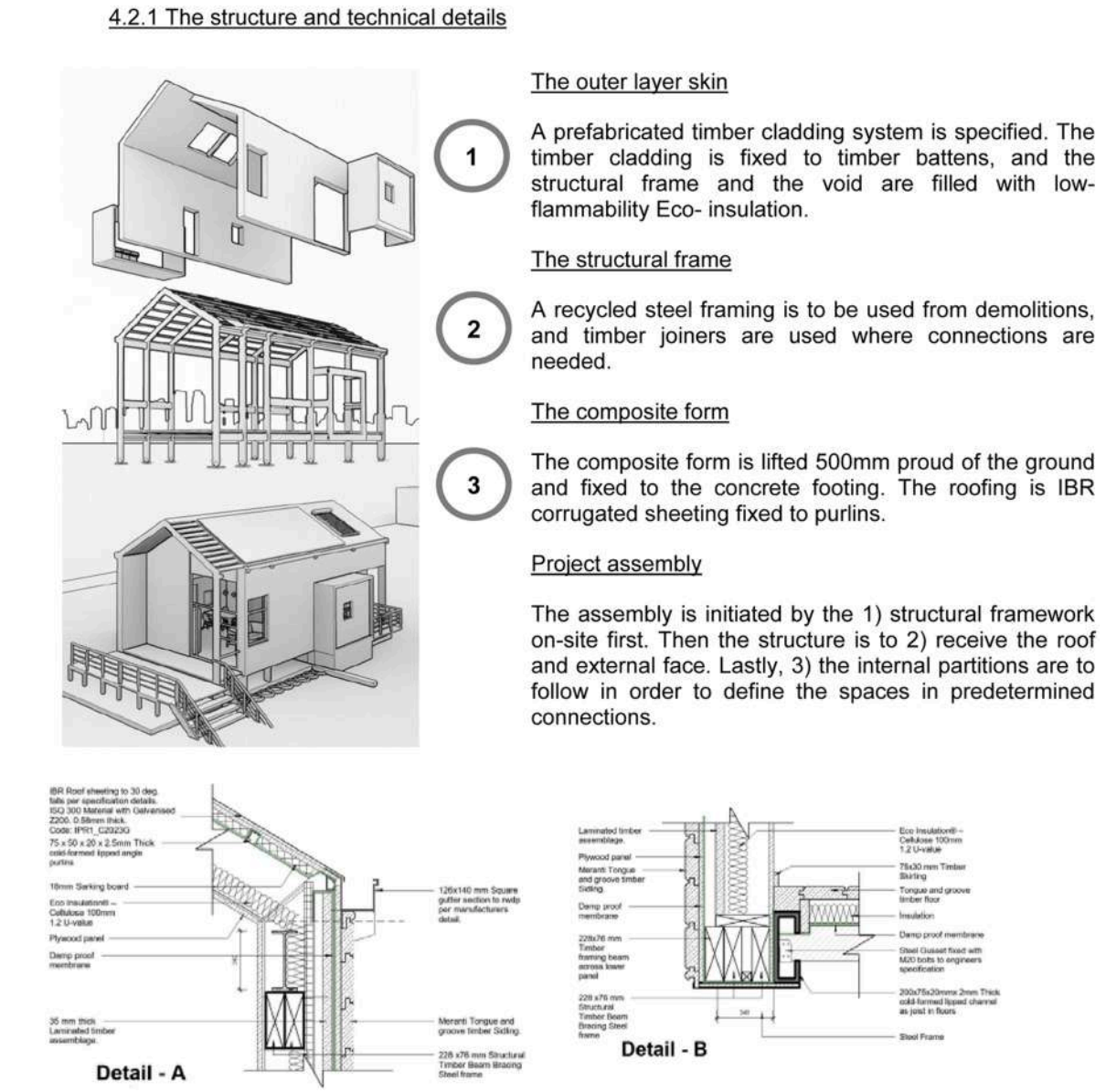

Fig. 5. Structural details and strategy of the construction of the project.
Source Phiri and Bosa. 2021.

solutions also considers adaptable systems, i.e., drought relief and flood mitigation.

The energy use concept

The energy use concept is based on the source of energy generation, preservation and usage. A multi-prong approach is taken by introducing multiple energy sources for general and specific needs. The SIAH-Livable House will make use of renewable energy. This is achieved through the specification of a solar PV system with an inverter and battery bank. The system will incorporate back-to-grid connections to municipal-supplied electricity. The renewable energy systems in SIAH Livable House will provide electricity to most power sockets for general use and LED lighting. Low-energy fittings and appliances will be encouraged to preserve energy as needed (See Fig. 6). The main draw on electrical supply is attributed to water heating which is supplemented by a solar thermal geyser system. The other major electrical draw, the stove, will use biogas, envisioned as a locally generated resource.

The water use concept

The water-use concept relies on alternating between municipal supply and stormwater collected in a rainwater tank. The use of water in the house is split into two criteria, potable and non-potable. Potable water usage is directed towards the supply of water to the

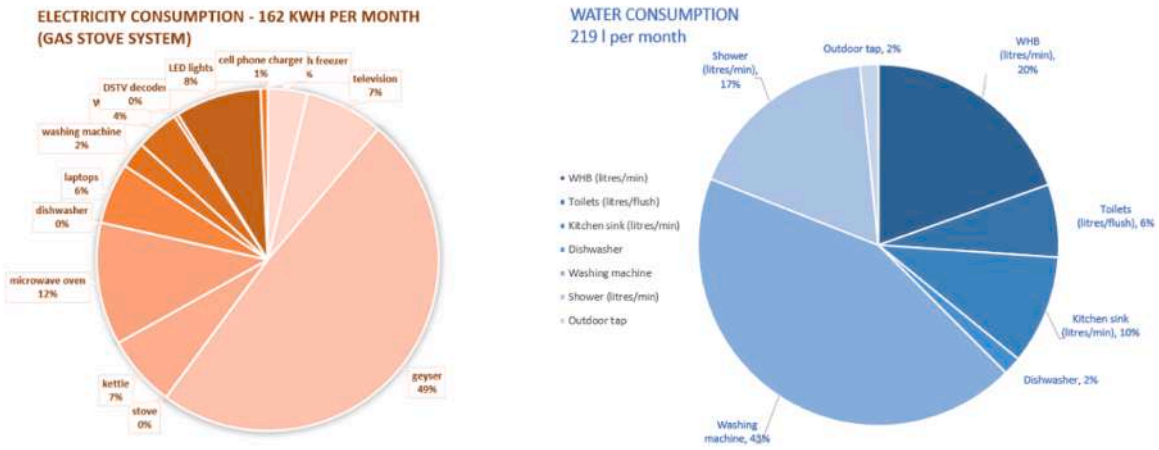

Fig. 6. Projected energy and water consumption.
Source Phiri and Bosa. 2021.

kitchen and bathroom sinks, the shower and the bath. Non-potable water usage is directed to the water supply of the toilet, the washing machine and the aquaponics system. Non-potable wastewater drainage is redirected to three different areas. Black water from the kitchen sink, toilet and washing machine is directed to municipal centralised treatment systems. The grey water from the bathroom sink, shower and bath is directed to a sand filter that feeds the filtered water into the non-potable water supply. Water from the aquaponics system will be rich in nutrients and is therefore directed to the tyre garden (See Fig. 7).

The incorporation of innovation by incorporating sustainable solutions to housing

A key aspect of the SIAH-Livable design is embodied by the incorporation of small-scale, 'beginner's' aquaponic systems that introduce urban agriculture to a given community. The aquaponic systems offer households access to growing vegetation and fish simultaneously. Understanding the system imparts a practical education in fish farming and balanced ecosystems. This system has a high initial cost but is fairly low cost to maintain. It can prove invaluable to a community struggling to meet its day-to-day needs. Water filtration is needed when water reuse is considered. During times of drought, stormwater capture can serve to do much more than watering gardens and washing clothes. By introducing localised filtration in low-income homes, a household can make use of water stored over from seasonal rain during the onset of dry weather months. This is another learnable process that can help communities benefit directly from abundant waterways.

The embodied energy of the materials specified is based on their suitable regional thermal performance as well as the optimum ecological and environmental sustainability targets. The design process incorporated materials that were locally available but also within a minimal travel radius. Once housing systems are formally set up the use of recycled material and the prefabrication of components near the site would also go a long way in the reduction of cost and carbon footprint.

As shown in Fig. 8, conventional water consumption in low-cost housing is based on the specification and use of common and affordable sanitaryware. A conventional house with 4 occupants will typically use 181 kL/year, which amounts to 496 litres a day. With the incorporation of passive design principles, recycling and filtering of stormwater the SIAH-Livable House will use 80 kL/year, which is 219 litres a day. As shown in Fig. 7, the 55,17% saving of water in its consumption will be a major improvement to the lives of the inhabitants because it brings the lifecycle cost and overall cost of living down. This approach also ensures a low impact on the environment and reduces potential pollution of nearby water systems. This significantly improves the sustainability and affordability of a house. This finding is aligned with Moghayedi et al. [7].

The energy use of a conventional home is often influenced by the ease of installation, the cost of materials and the ease of access to energy system components. The rate of energy use in conventional homes is linked to the heating and cooling of the home, the draw of general appliances on the energy source, the amount of amenities, lighting and the need for hot water. The use of energy is based on basic needs and also energy for comfort. In a conventional home, the energy used for basic needs is 34 kWh/m2/year which amounts to 93 Wh/m2/year. The thermal comfort of a conventional home uses 41 kWh/m2/ year. The SIAH-Livable House uses less energy for basic needs, 18 kWh/m2/year, but requires more energy for thermal comfort which requires 43 kWh/m2/year. However, the energy use from the SIAH-Livable design is 21,06% lower than the conventional home. This is made possible by the production of renewable energy through solar energy systems (See Fig. 7).

The embodied energy of materials is a constant concern for the environment. Looking at the material a conventional home uses for roof, floor, external and internal walls finish, windows, doors and insulation it amounts to 5962 MJ/m2 (See Fig. 7). The SIAH-Livable with the specification of recycled and locally sourced material has an embodied energy of 1687 MJ/m2 which is a 66,9% saving of the material's energy efficiency. The results from the SIAH-Liveable House's water and energy savings allow the occupants to save on living costs and therefore assist in the affordability of the house. The embodied energy of the materials used in the specification of the SIAH-Livable House supports the sustainable requirement of SIAH, which is the alleviation of environmental pressures that building resource requirements impose. The overall analysis and comparison of SIAH-Livable to conventional houses prove that the utilisation

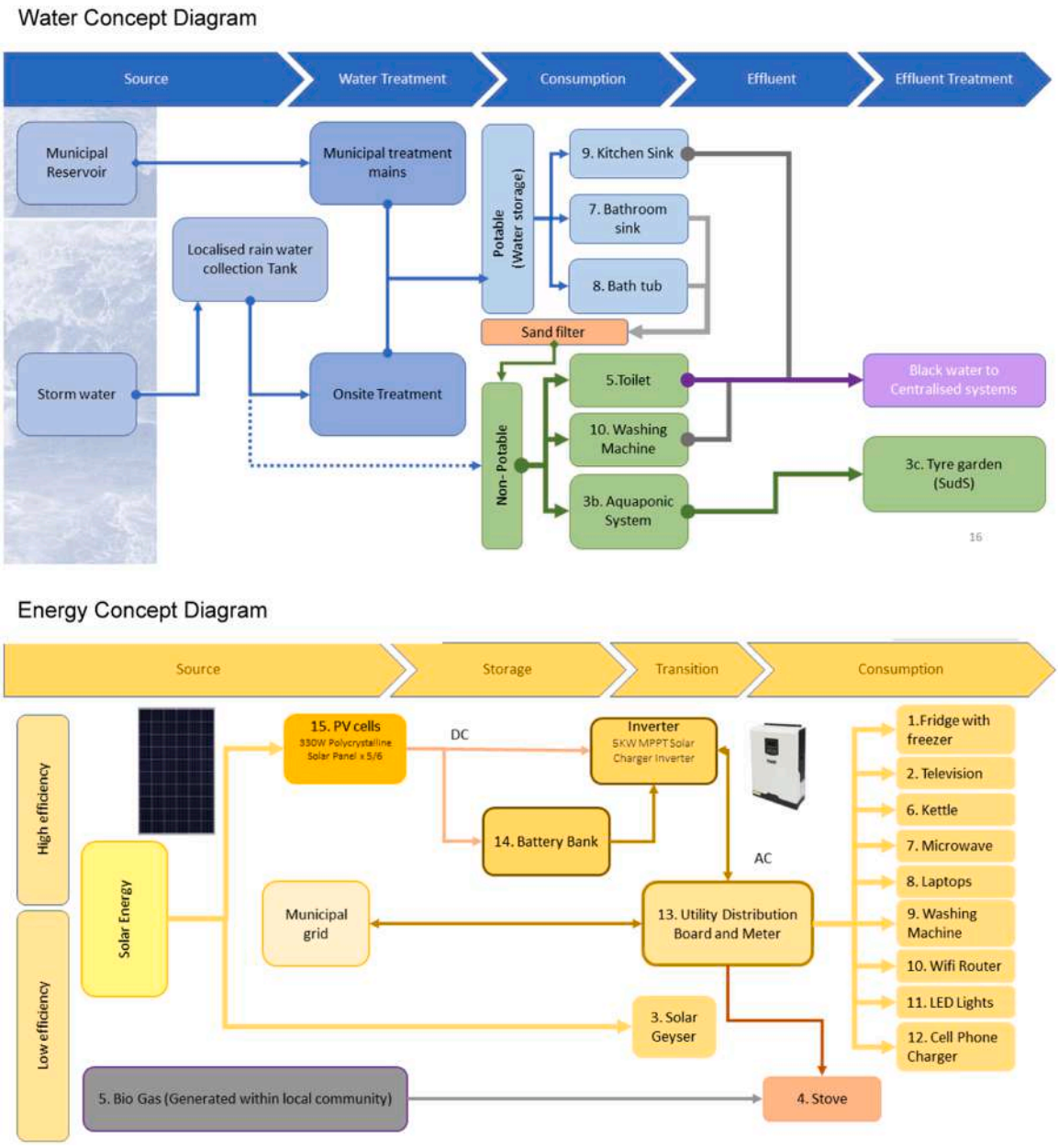

Fig. 7. Energy and water usage design concepts.
Source Phiri and Bosa. 2021.

of passive design methods, new building materials (including recycled and local materials) and innovative building technologies can have a significant impact on the social, environmental, and economic sustainability of houses. This keeps with phenomena observed by Moghayedi et al. [22] and Windapo et al. [25].

Construction cost

Affordability is a huge factor in the SIAH-Livable' s specification and design process. Markets are unfavourable for a timber build as it is hard to find a suitable composite padding system in South Africa that matches the insulative values of systems used in Europe. A lot of costs will be mitigated in the use and procurement of recycled materials and low labour costs from an established fabrication line. The total cost based on R5000 per square metre is R276 000 excluding vat, which still falls under the classification of an affordable house for South African low-to-middle income households. It should be noted that the operation cost and therefore the lifecycle cost of SIAH-Livable House accrues costs well below those of a conventional house. Additionally, the emphasis on durable construction and

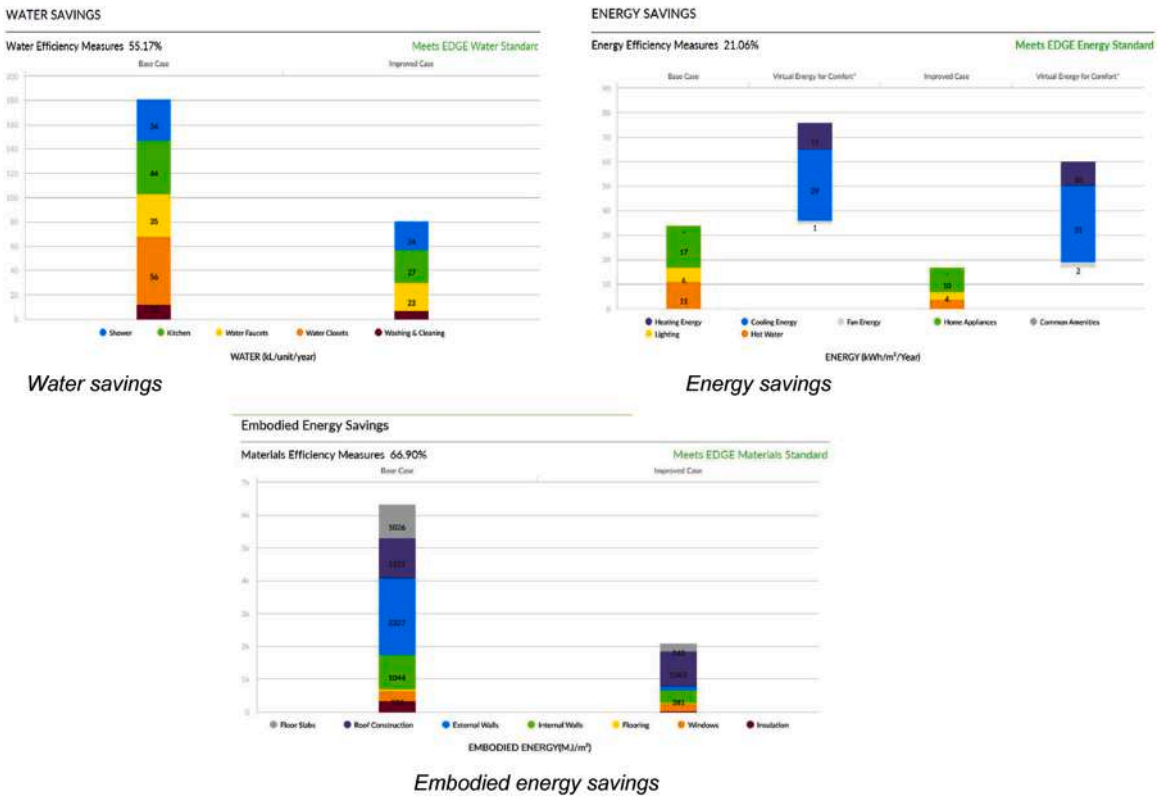

Fig. 8. Building performance of SIAH-Livable.

long-term affordability ensures that the SIAH-Livable House remains a sustainable solution for African communities. Such a system could foster social equity and provide more Africans access to comfortable and energy-efficient housing. These findings verify the importance of the operational cost of a house when considering affordability as also stated by various scholars [9].

Conclusion and recommendations

The need for affordable and sustainable housing is a global phenomenon. However, affordability and sustainability as concepts have not always been easy to achieve in housing developments. With the incorporation of sustainability in affordable housing with the use of innovative technologies the SIAH case study house as a concept design aims to achieve both criteria for affordability and sustainability. The outcome of the specified water concept, system and components allows for 55.7% efficiency in comparison to conventional water system measures. The SIAH-Liveable water usage output meets the EDGE water standards. The energy usage concept, system and components allow for a 21,06% efficiency in comparison to the conventional energy source and use measures. The SIAH-Livable energy usage output meets the EDGE water standards, by using passive heating and cooling systems, renewable PV cells energy sources for general electricity use, biogas for cooking and a solar geyser for hot water. The initial SIAH-Livable cost is slightly higher in comparison to a conventional low-cost dwelling however the sustainable principles introduced and specified by the SIAH-Livable increase the value in the long run. The EDGE scores provided of the water, energy and material embodied concepts will be used for the design of a net-zero SIAH house.

The current research significantly advances understanding of the association between sustainability and affordability in South African housing design. While similar studies have explored sustainability or affordability in isolation, this research uniquely bridges the gap by explicitly focusing on the intersection of these two critical aspects. By investigating the specific context of South African housing design, this research contributes to the existing literature by providing insights and findings directly applicable to the local context. This is important because housing challenges and socio-economic dynamics vary across different regions, and a tailored approach is necessary to address the specific needs and constraints of South African communities. This approach is in line with Agenda 2063′s focus on promoting inclusive development that takes into account the unique socio-economic dynamics of African nations. By developing housing solutions that are both sustainable and affordable, tailored to the local context, African countries can address the housing challenges faced by their populations, contributing to the broader objectives of Africa's Union's Agenda 2063.

Furthermore, this research delves into the complexities of sustainability and affordability in housing design, considering factors such as energy efficiency, resource conservation, optimal space utilization, affordable construction techniques, and social equity. By comprehensively examining these interconnected elements, this study offers a holistic perspective that goes beyond a singular focus on

either sustainability or affordability. The study's findings provide valuable insights into innovative strategies, best practices, and potential solutions for integrating sustainability and affordability in South African housing design. These insights have broader implications beyond South Africa and can be applied to other countries facing similar housing challenges. This knowledge-sharing k with Agenda 2063′s vision of promoting African solidarity and integration. By informing policymakers, architects, developers, and other stakeholders in the housing sector, these findings enable them to make informed decisions and implement effective measures to address the urgent need for sustainable and affordable housing solutions across Africa and beyond. This aligns with Agenda 2063′s emphasis on effective governance, policy coherence, and evidence-based decision-making to drive socio-economic transformation. The research directly contributes to several Sustainable Development Goals (SDGs), such as SDG 7 (Affordable and Clean Energy), SDG 10 (Reduce inequality), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action) through exploring energy efficiency, resource conservation, and social equity in the context of South African housing. By implementing the findings of this research, African countries can progress towards the SDGs outlined in Africa's Union's Agenda 2063.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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