DIGITAL ARCHITECTURAL STRATEGIES FOR AFFORDABLE AND CLIMATE-RESPONSIVE HOUSING IN SOUTH AFRICA

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Abstract: *South Africa faces a persistent affordable housing challenge in which housing shortages, informal settlement growth, environmental vulnerability, and limited household resources intersect. Conventional housing approaches often prioritize the delivery of standardized units, while providing limited capacity to respond simultaneously to local climatic conditions, spatial constraints, and changing household needs. Digital architectural technologies offer an opportunity to move beyond standardized housing provision by enabling data-driven, adaptable, and performance-oriented design strategies. This study aimed to formulate digital architectural strategies for developing affordable and climate-responsive housing appropriate to the South African context. The research employed a qualitative integrative literature review, examining studies on digital architecture, computational and parametric design, building information modelling (BIM), environmental simulation, affordable housing, informal settlements, and climate adaptation in South Africa. The literature was thematically analyzed to identify relationships between digital design capabilities, housing affordability, climatic performance, and contextual adaptability. The results indicate that the most relevant digital architectural strategies comprise four interconnected components: context-based computational design for generating adaptable housing configurations; environmental performance simulation for optimizing thermal comfort, ventilation, solar exposure, and energy demand; BIM-supported material and construction assessment for improving cost efficiency; and participatory digital design for incorporating household needs and incremental housing practices. The study further indicates that digital architecture is most effective when digital technologies are integrated with local climatic, socioeconomic, and spatial conditions rather than applied as stand-alone technological solutions. The resulting framework positions digital architecture as a decision-support approach for producing housing that is not only digitally optimized but also affordable, climate-responsive, and adaptable to the realities of South African communities.*

Keywords: *Digital architecture; Affordable housing; Climate-responsive design; Informal settlements; South Africa*.

1. Introduction

The quality of the indoor environment is an important Housing in South Africa represents more than a shortage of physical dwellings; it reflects the intersection of spatial inequality, household affordability, environmental vulnerability, and the persistent growth of informal settlements. Although substantial efforts have been made to expand housing provision, many low-income households continue to live in environments where inadequate construction quality, limited infrastructure, overcrowding, and exposure to climatic hazards remain interconnected problems. This situation creates a fundamental challenge for architectural practice: how can affordable housing be designed not merely as a low-cost product, but as an adaptable living environment capable of responding to the climatic, spatial, economic, and social realities of its occupants? Addressing this question requires a shift from standardized housing provision toward design approaches that can accommodate local conditions and generate alternative solutions efficiently. Digital architecture provides an important opportunity for such a shift because computational design, environmental simulation, BIM, GIS, and digital fabrication can connect architectural decision-making with measurable environmental and socioeconomic parameters.

The physical conditions of South African informal settlements illustrate the urgency of this challenge. Dense settlement patterns, small dwelling footprints, lightweight construction, limited vegetation, and insufficient infrastructure can increase exposure to heat and other environmental stresses. These characteristics are particularly significant because low-income households often have fewer financial resources to modify their homes or acquire mechanical cooling and heating systems. Research on low-cost housing in Johannesburg found substantial indoor temperature variations and highlighted the vulnerability of occupants to uncomfortable thermal conditions [1]. Similarly, recent research mapping climate-change impacts in South African informal settlements identified heat, flooding, and drought among the major hazards affecting these communities, while socioeconomic and infrastructural constraints further increase their vulnerability [2].

Figure 1. Examples of informal and low-income housing conditions in South Africa.

Climate vulnerability therefore needs to be considered simultaneously with housing affordability. In Tshwane, for example, informal settlements have been identified as exposed to cascading and cumulative climate-related risks associated with settlement location, housing characteristics, infrastructure deficiencies, and socioeconomic conditions [3]. Such conditions indicate that simply increasing the number of housing units does not necessarily produce resilient housing. Architectural decisions concerning orientation, roof configuration, shading, ventilation, material selection, thermal mass, and spatial organization can significantly influence indoor environmental conditions. Kimemia *et al.* demonstrated that passive cooling interventions could substantially improve thermal comfort in informal housing [4]. More recent research using simulation-based approaches has further demonstrated that roof-based interventions can reduce excessive heat exposure in informal dwellings [5]. These findings establish an important foundation for integrating environmental performance analysis into the architectural design process.

At the same time, digital architectural technologies have expanded the possibilities for generating and evaluating design alternatives. Computational and parametric design can translate environmental, spatial, and geometric parameters into alternative design configurations, while building performance simulation can assess their thermal and energy implications before construction. A particularly relevant example is the computational urban design research conducted in Cape Town by Miao *et al.*, which demonstrated how computational methods could generate alternative configurations of roads, blocks, plots, and buildings according to specified planning parameters [6]. This approach is significant because informal settlements are spatially heterogeneous, meaning that a single standardized housing configuration may not respond effectively to different site conditions.

Digital technologies can also contribute to the economic dimension of affordable housing. Building Information Modelling (BIM), GIS, UAV-based data acquisition, artificial intelligence, 3D printing, smart sensors, modular construction, and prefabrication have increasingly been identified as technologies capable of improving housing delivery and construction efficiency in South Africa [7]. Research on 3D printing, for instance, has identified its potential for low-income housing while simultaneously emphasizing the importance of technological capacity, training, institutional support, and affordability [8]. These findings demonstrate that digitalization should not be understood simply as the introduction of advanced technologies into architectural practice. Its value depends on whether technology can reduce costs, improve performance, accelerate construction, and respond to the needs of communities.

Another important issue is the role of residents in shaping affordable housing. Informal housing in South

Africa is frequently modified incrementally by its occupants as household needs, economic circumstances, and spatial requirements change. Research on proximal design has shown that residents can act as active designers of their built environment rather than merely as passive recipients of professionally designed housing [9]. This finding challenges conventional top-down approaches and suggests that digital architectural strategies should accommodate user participation and incremental adaptation. A digitally generated housing solution that performs well environmentally but cannot be modified according to household needs may have limited practical relevance.

The state of the art therefore reveals three important research streams. The first concerns climate-responsive housing, which has demonstrated the thermal and environmental vulnerability of low-income and informal dwellings [1]–[5]. The second concerns computational and digital design, which has demonstrated the capacity of digital systems to generate and evaluate multiple spatial configurations [6]. The third concerns digital construction and housing delivery, in which BIM, GIS, 3D printing, prefabrication, and related technologies are increasingly explored as mechanisms for improving affordability and efficiency [7], [8], [10]. However, these research streams remain largely fragmented. Environmental studies frequently concentrate on individual building interventions, computational studies emphasize design generation, while digital construction studies focus on production and delivery. There remains limited integration of these dimensions into a coherent architectural strategy specifically addressing the combined challenges of affordability, climate responsiveness, and contextual adaptability in South African housing.

This research therefore aims to formulate digital architectural strategies for affordable and climate-responsive housing in South Africa by synthesizing computational design, environmental performance evaluation, affordability considerations, and user-contextual requirements. The study addresses two research questions: (1) How can digital architectural technologies be integrated to develop housing strategies that are simultaneously affordable and climate-responsive in the South African context? and (2) Which architectural and contextual parameters are most important for developing digitally supported housing strategies for low-income and informal communities in South Africa?

The research is expected to contribute both theoretically and practically. Theoretically, it extends the discourse on digital architecture by connecting computational design with housing affordability and climate resilience in a developing-country context. Practically, it provides a basis for architects, planners, housing authorities, and other stakeholders to evaluate alternative housing strategies before construction. The novelty lies in positioning digital architecture not simply as a representation or production technology, but as an integrated decision-support strategy linking computational design, climate-performance assessment, affordability, and user context. Through this approach, digital architecture can move beyond standardized digital production toward housing solutions that are adaptive, environmentally responsive, economically realistic, and more closely aligned with the realities of South African communities.

2. Research Methods

This study employed a qualitative integrative literature review combined with thematic synthesis and framework development to formulate digital architectural strategies for affordable and climate-responsive housing in South Africa. The method was designed to connect four analytical domains: digital architectural technologies, housing affordability, climate-responsive design, and contextual/user requirements.

The study was conducted in four sequential stages. The first stage was literature identification and selection. Relevant peer-reviewed publications were identified through Google Scholar, Scopus-indexed literature, ScienceDirect, SpringerLink, Taylor & Francis, and major architectural and built-environment databases. The search focused on publications addressing South African housing, informal settlements, affordable housing, climate adaptation, computational design, parametric architecture, BIM, GIS, environmental simulation, digital fabrication, and participatory digital design. Studies were included when they provided direct evidence concerning housing conditions, digital design applications, environmental performance, construction affordability, or community adaptation in South Africa. Publications unrelated to housing, lacking a clear methodological basis, or addressing digital architecture without relevance to the identified housing problems were excluded.

The second stage involved thematic coding. Extracted findings were organized into four principal categories: (1) spatial and socioeconomic constraints, (2) climatic and environmental risks, (3) digital architectural capabilities, and (4) implementation and user requirements. Within these categories, specific design parameters were identified, including density, site configuration, orientation, shading, ventilation, roof design, thermal performance, material selection, construction cost, modularity, expandability, and household preferences.

The third stage consisted of cross-domain synthesis, in which relationships between identified problems and potential digital responses were systematically mapped. For example, thermal vulnerability was linked to environmental simulation, spatial constraints to computational design, cost limitations to BIM-based evaluation, and changing household requirements to participatory and incremental design.

The final stage was framework development. The synthesized relationships were organized into a digital architectural strategy framework connecting contextual data, computational design generation, environmental evaluation, affordability assessment, and user requirements. The framework was then assessed for internal consistency by comparing each proposed strategy against the identified South African housing problems. The final output was a context-specific framework explaining how digital architectural technologies can support affordable, climate-responsive, and adaptable housing.

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3. Discussion

The literature synthesis indicates that digital architecture can contribute to affordable and climate-responsive housing when digital technologies are integrated with climatic, socioeconomic, spatial, and household conditions rather than being treated as independent technological solutions. The findings suggest that affordability and climate responsiveness should be considered simultaneously because improving thermal performance may require additional materials or construction measures, while minimizing initial construction cost may result in poor indoor environmental conditions. Therefore, the main contribution of the proposed strategy is not the use of a particular software platform, but the integration of contextual data, parametric design, environmental evaluation, cost assessment, and spatial adaptability within a single decision-support process. This interpretation directly addresses the first research question concerning how digital architectural technologies can be integrated to develop housing strategies that are simultaneously affordable and climate-responsive in South Africa.

The first stage of the proposed framework is contextual data acquisition. The synthesis demonstrates that digital design should begin with information about climatic conditions, site characteristics, existing housing morphology, construction materials, and household requirements. This is particularly important in South African informal and low-income settlements, where housing performance is strongly influenced by material choices, settlement density, building orientation, and the ability of households to modify their dwellings over time. Ground-level research in Tshwane has demonstrated that informal dwellings can experience substantial heat-stress exposure and that the spatial and material characteristics of these dwellings influence indoor environmental conditions [17]. Similarly, research on climate adaptation in South African informal settlements emphasizes that responses to heat stress need to be related to the physical characteristics of dwellings and the circumstances of their occupants [13]. These findings indicate that construction materials, site conditions, and household requirements should become initial inputs rather than secondary considerations.

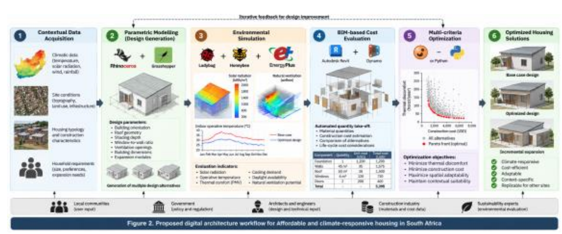

Figure 2. Proposed digital architecture workflow for affordable and climate-responsive housing in South Africa.

The integration of these contextual inputs with digital design processes is illustrated in Figure 2. The proposed workflow begins with contextual data acquisition and subsequently connects these data to parametric design, environmental simulation, BIM-based cost assessment, multi-criteria optimization, and the generation of optimized housing alternatives. The workflow is intentionally iterative because housing design decisions can generate trade-offs between thermal performance, construction cost, spatial quality, and adaptability. Parametric modelling provides a mechanism for managing these trade-offs by allowing several design variables to be modified simultaneously and systematically. Previous studies have demonstrated that parametric building information modelling can support automated multi-objective optimization by linking design parameters with performance criteria [11]. Similarly, integrated parametric approaches using environmental simulation and machine-learning-supported optimization have demonstrated the potential to evaluate multiple building performance criteria during the design process [12]. Therefore, the proposed workflow extends the role of digital architecture from geometric representation toward performance-informed decision making.

Parametric modelling is particularly relevant to affordable housing because standardization does not necessarily have to mean repetition of a single fixed housing type. Instead, a parametric model can define a family of housing configurations in which selected variables are allowed to change according to site and household conditions. Building orientation, roof geometry, shading depth, window-to-wall ratio, ventilation openings, building dimensions, and expansion modules can therefore be treated as adjustable parameters. This approach provides an opportunity to retain construction logic and modularity while allowing the resulting housing units to respond to local climatic and spatial conditions. Research on performance-driven form finding has similarly shown that parametric modelling combined with energy simulation and evolutionary optimization can generate and compare alternative building forms systematically [20]. The significance of this approach for South African housing is that design variation can be introduced without abandoning the efficiency associated with standardized construction systems.

The environmental simulation stage is important because climate responsiveness should be evaluated rather than assumed. Ladybug and Honeybee can provide a computational interface for assessing climatic variables and connecting parametric building models with simulation engines such as EnergyPlus. The proposed evaluation should consider solar radiation, indoor operative temperature, thermal comfort, daylight availability, cooling demand, and natural ventilation potential. A parametric optimization framework using daylight and energy simulation demonstrates how environmental performance can be incorporated into early-stage residential design decisions [19]. More recent research has further demonstrated that simulation-based optimization can integrate building energy performance with urban heat-island effects and future climate scenarios [15]. This is particularly relevant for South African cities because climatic stress is not distributed uniformly across urban areas, and informal settlements may experience additional exposure because of settlement morphology, material conditions, and limited adaptive capacity.

The South African evidence reinforces the need for this performance-based approach. Studies of informal settlements have documented substantial heat exposure and inadequate indoor environmental conditions, indicating that housing interventions cannot be evaluated solely in terms of whether a dwelling has been constructed or whether its initial cost is low [17].

Roof-based adaptations have also been examined as mechanisms for reducing heat-stress exposure in informal dwellings, demonstrating the importance of envelope and roof characteristics in climate adaptation [14]. Consequently, parameters such as roof geometry, shading, ventilation openings, and envelope properties should be included within the digital model rather than evaluated only after a housing type has been selected. The environmental simulation stage therefore acts as a bridge between architectural form and measurable climatic performance.

The integration of environmental simulation with optimization is particularly important because the most thermally effective solution may not be the most affordable solution. A design with extensive shading, increased insulation, larger ventilation openings, or more complex geometry may improve thermal performance but simultaneously increase construction cost. Multi-objective optimization can make these trade-offs explicit by identifying a set of alternative solutions rather than assuming that one design criterion should dominate all others. Research on multi-objective building optimization under urban heat-island conditions demonstrates the usefulness of combining simulation, optimization, and future climate scenarios when evaluating energy-efficient building solutions [15]. Similarly, BIM-enabled optimization has shown that parametric building information can be connected with performance analysis to support more systematic design decisions [16]. For affordable housing, this means that the optimization objective should not be limited to minimum energy consumption; it should include construction cost, thermal comfort, spatial adaptability, and contextual suitability.

The relationship between the principal design parameters, housing problems, digital tools, and evaluation indicators is summarized in Table 1.

Table 1. Digital architectural parameters and their relationship to affordable and climate-responsive housing in South Africa

Design parameter	Housing problem addressed	Proposed digital tool	Evaluation indicator
Building orientation	Solar heat gain and poor climatic response	Rhino + Grasshopper; Ladybug/Honeybee	Solar radiation; operative temperature; thermal comfort
Roof geometry	Heat accumulation and solar exposure	Grasshopper; Ladybug/Honeybee	Roof solar exposure; operative temperature
Shading depth	Excessive solar heat gain	Grasshopper; Ladybug	Solar radiation; shading effectiveness
Window-to-wall ratio	Thermal gain and daylight imbalance	Grasshopper; EnergyPlus	Thermal comfort; daylight; energy demand
Ventilation openings	Insufficient natural ventilation	Grasshopper; Honeybee/EnergyPlus	Airflow potential; thermal comfort
Envelope material	Heat transfer and high construction cost	Revit + Dynamo; EnergyPlus	Thermal transmittance; material quantity; cost
Building compactness	Material inefficiency and heat gain	Grasshopper; Revit	Surface-to-volume ratio; material quantity; cost
Building spacing	Poor airflow and solar access	Rhino/Grasshopper; GIS	Solar access; airflow potential; density
Incremental expansion	Changing household spatial needs	Grasshopper; Revit	Expansion capacity; floor area; adaptability
Material quantity	High construction expenditure	Revit + Dynamo	Quantity take-off; construction cost
Construction system	High labour/time and implementation constraints	BIM; cost database	Construction time; cost; local feasibility

As indicated in Table 1, different architectural variables respond to different housing problems and should therefore not be treated as isolated design features. Building orientation affects solar exposure and indoor thermal conditions, while roof geometry and shading depth influence heat gain and solar protection. Window-to-wall ratio and ventilation openings influence daylight and airflow but also have implications for construction cost, privacy, and security. Building compactness and spacing can influence both material efficiency and environmental performance. Incremental expansion is particularly important because low-income households may modify or extend their dwellings over time. The digital model should therefore be capable of representing not only the initial housing unit but also potential future configurations. This approach changes the definition of affordability from the cost of a single completed dwelling toward the longer-term capacity of a housing system to accommodate household change.

The affordability dimension also requires careful consideration of construction technology. Digital fabrication and 3D-printing technologies have received increasing attention in African housing research because they may reduce construction time and material waste. However, the literature indicates that technological innovation does not automatically guarantee affordability. A comprehensive assessment of 3D-printing technology for affordable housing in Africa identified potential environmental and construction advantages but also highlighted the importance of technology availability, material supply, and life-cycle economic considerations [18]. This finding is significant for the proposed digital architecture framework because cost evaluation should not be separated from the technological context in which a housing system will be implemented. The BIM-based stage should therefore incorporate locally available materials, local unit prices, construction methods, transportation requirements, and maintenance considerations wherever possible.

The use of BIM and Dynamo in the proposed workflow provides a mechanism for connecting design geometry with quantity and cost information. Autodesk Revit can represent the building components, while Dynamo can support automated quantity extraction and the comparison of alternative material configurations. The purpose is not simply to produce a more detailed digital model, but to establish a direct relationship between design modifications and their economic consequences. For example, changing the roof configuration in a parametric model may influence roof area, structural components, material quantities, and construction cost. Such changes can then be compared against their environmental performance. This approach is consistent with the broader development of BIM-enabled multi-objective optimization, in which building information and computational analysis are integrated to improve design decision making [16].

The software workflow proposed in this research is therefore an operational interpretation of the conceptual framework. It should be understood as a recommended digital workflow for future design implementation rather than as a claim that all software procedures were experimentally executed within the present literature review. Rhino and Grasshopper can be used for parametric modelling and design generation, allowing architectural variables such as building orientation, roof geometry, shading depth, window-to-wall ratio, ventilation openings, and building dimensions to be systematically modified. Ladybug and Honeybee, coupled with EnergyPlus, can subsequently be used to evaluate solar radiation, indoor operative temperature, thermal comfort, daylight availability, and energy demand. The generated alternatives can then be developed in

Autodesk Revit for BIM-based modelling, while Dynamo can automate material quantity extraction and support construction cost estimation. Finally, Galapagos or another suitable evolutionary optimization algorithm can be used to evaluate alternative solutions according to thermal performance, construction cost, and spatial adaptability. The integration of these tools creates an iterative workflow in which simulation and cost results can inform subsequent modifications of the parametric model.

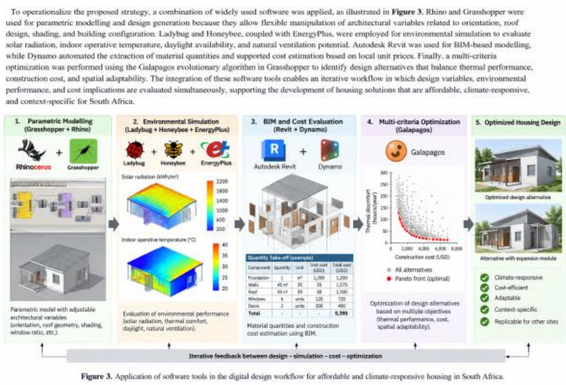

Figure 3. Application of software tools in the digital design workflow for affordable and climate-responsive housing in South Africa.

The use of evolutionary optimization is especially relevant when several design variables interact in nonlinear ways. Recent work combining parametric modelling, energy simulation, and genetic algorithms demonstrates how building geometry can be systematically evaluated to identify lower-energy configurations [20]. A regulation-aware generative design framework has similarly demonstrated the potential for combining BIM, generative design, and multi-objective optimization to evaluate sustainable residential building alternatives [21]. For the proposed South African framework, however, optimization should not be defined exclusively by energy performance. The objective function should also include construction cost and adaptability because the purpose is to develop housing solutions that can be implemented within constrained household and construction environments. This distinction is important because a technically optimal building may still be unsuitable if it requires expensive materials, complex construction techniques, or specialist skills that are unavailable locally.

The proposed framework also provides an opportunity to incorporate future climate resilience. Digital twin technologies can extend the digital workflow beyond the initial design stage by enabling the digital representation of housing performance during operation. Recent research involving housing in South Africa has explored the integration of climate resilience and digital twin technologies and has demonstrated the potential of digital models to support environmental performance assessment and sustainable housing strategies [22]. Although a complete digital twin is beyond the scope of the present literature-review study, the concept provides an important direction for future research. A housing model could potentially be updated using post-occupancy information, allowing subsequent design iterations to be informed by actual thermal conditions, energy use, water consumption, maintenance requirements, and household modifications. Such a feedback mechanism would strengthen the relationship between design prediction and real housing performance.

The second research question concerns which architectural and contextual parameters are most important for developing digitally supported housing strategies for low-income and informal communities in South Africa. The synthesis indicates that these parameters can be grouped conceptually into four interconnected domains: climatic parameters, architectural parameters, economic and material parameters, and household or contextual parameters. Climatic parameters include solar exposure, outdoor temperature, wind conditions, rainfall, and heat-stress risk. Architectural parameters include orientation, roof geometry, shading, openings, building compactness, ventilation, and expansion capacity. Economic and material parameters include material availability, quantity, construction cost, construction technology, and maintenance requirements. Household and contextual parameters include household size, spatial preferences, incremental change, settlement morphology, infrastructure availability, and community practices. Their integration is essential because housing performance results from the interaction between physical design and the conditions in which the dwelling is occupied.

The importance of these contextual parameters is reinforced by evidence that socioeconomic vulnerability influences the capacity of informal settlements to respond to climate-induced hazards [24]. Consequently, a digitally optimized housing solution cannot be considered successful solely because it achieves better simulated thermal or energy performance. The solution must also be feasible within the socioeconomic and infrastructural conditions of the community. This requirement distinguishes the proposed approach from technology-centred digital design models that focus primarily on computational optimization. Digital tools should support contextual decision making rather than replace local knowledge or community participation. In this respect, digital architecture becomes a means of organizing and evaluating different forms of knowledge within the housing design process.

The framework therefore positions local communities, architects, engineers, government institutions, construction industries, and environmental specialists as complementary stakeholders. Community input is particularly important for determining household requirements and incremental housing practices, while government and professional stakeholders can establish regulatory and technical constraints. Construction stakeholders can provide realistic information concerning materials, costs, labour, and construction methods, while environmental specialists can support the interpretation of simulation results. The resulting process is therefore not purely computational but socio-technical, with digital tools acting as a platform through which different forms of knowledge can be integrated. This is particularly relevant in low-income and informal settlements, where the distinction between formal design and user-driven adaptation may be less clear than in conventional housing development.

Another important implication concerns the relationship between housing affordability and adaptability. Conventional affordability assessments often focus on the initial cost of delivering a dwelling. However, a housing unit that is inexpensive to construct but difficult to modify may become economically inefficient when household size, income, or functional requirements change. The proposed parametric approach allows incremental expansion to be considered as part of the initial design logic. For example, an initial unit can be configured with predefined structural and spatial conditions that permit future extensions without requiring major reconstruction. Digital modelling can therefore evaluate both the initial configuration and possible future states. This creates a broader interpretation of affordability in which adaptability becomes an economic as well as a spatial attribute.

The framework also has implications at the settlement scale. Although the proposed workflow primarily addresses housing design, contextual data can be extended through GIS-based analysis to evaluate settlement density, building spacing, solar exposure, accessibility, infrastructure conditions, and exposure to climate-related hazards. This is important because the environmental performance of an individual dwelling is partly influenced by its surrounding built environment. Closely spaced dwellings, for example, can modify airflow and solar access, while settlement location can influence exposure to flooding or other hazards. Socioeconomic and spatial vulnerability in South African informal settlements therefore needs to be considered alongside individual building performance [24]. Integrating settlement-scale information with building-level parametric modelling could provide a more comprehensive basis for future housing strategies.

Overall, the findings answer the first research question by indicating that digital architectural technologies can be integrated through an iterative sequence of contextual data acquisition, parametric design generation, environmental simulation, BIM-based cost evaluation, and multi-criteria optimization. The answer to the second research question is that climatic exposure, building orientation and form, envelope and ventilation characteristics, material and construction cost, spatial adaptability, settlement conditions, and household requirements are the principal parameters that should be incorporated into the digital design process. The novelty of the proposed framework lies in connecting these parameters rather than optimizing them independently. In this sense, digital architecture becomes a decision-support system for balancing competing requirements in affordable housing rather than merely a method for producing sophisticated digital representations.

Nevertheless, the framework has several limitations. First, its effectiveness depends on the availability and quality of climatic, spatial, material, and socioeconomic data. Second, simulation outcomes are sensitive to modelling assumptions, boundary conditions, and the accuracy of input data. Third, the availability of software expertise, computational resources, and appropriate digital infrastructure may restrict implementation in resource-constrained housing programmes. Fourth, optimization can produce technically efficient solutions that remain difficult to construct or maintain if local construction practices and material supply are not incorporated into the decision process. Finally, the proposed relationships between software, design parameters, and housing outcomes remain conceptual because the present study is based on an integrative literature review rather than empirical software-based testing. Future research should therefore validate the framework through case studies in different South African climatic regions and compare simulated results with monitored indoor environmental conditions, household feedback, and actual construction costs.

The principal implication of the study is that digital architecture should be understood as an integrated process of contextual analysis, computational design, environmental assessment, economic evaluation, and iterative optimization. For South African affordable housing, this approach offers a pathway beyond the conventional choice between standardized low-cost construction and technically advanced high-performance housing. Instead, it suggests that affordable housing can be systematically adapted to local climatic and socioeconomic conditions through digitally supported design decisions. The resulting framework provides a basis for developing housing alternatives that are climate-responsive, economically conscious, spatially adaptable, and sensitive to the realities of South African communities. The contribution is therefore not simply the recommendation of digital software, but the formulation of a context-sensitive design logic in which digital technologies are used to connect environmental performance, affordability, adaptability, and local housing requirements within a single architectural decision-making process.

4. Conclusion

This study concludes that digital architectural technologies can be integrated into a context-sensitive decision-support framework for developing affordable and climate-responsive housing in South Africa. The findings indicate that digital architecture is most effective when contextual data, parametric design, environmental performance assessment, cost evaluation, and spatial adaptability are connected within an iterative design process. Rather than treating digital technology as a tool for visualization alone, the proposed approach uses digital processes to compare alternative housing configurations and identify solutions that balance thermal performance, construction cost, and changing household requirements. The proposed workflow begins with climatic, spatial, material, and household data, followed by parametric design generation, environmental simulation, BIM-based cost assessment, and multi-criteria optimization. This integration provides a systematic basis for developing housing alternatives that are environmentally responsive while remaining sensitive to affordability constraints.

In response to the second research question, the study identifies climatic exposure, building orientation, roof geometry, shading, window-to-wall ratio, ventilation openings, envelope materials, building compactness, construction cost, material availability, settlement conditions, and incremental expansion capacity as important parameters for digitally supported housing design. Household requirements and local socioeconomic conditions are equally important because housing affordability and adaptability cannot be determined solely through building performance indicators. The study therefore establishes that affordable and climate-responsive housing requires a balance between environmental performance, economic feasibility, and long-term adaptability.

The main contribution of this study is the formulation of an integrated digital architectural strategy specifically oriented toward the South African housing context. The framework provides a basis for future empirical testing through case studies, environmental simulation, construction-cost validation, and post-occupancy evaluation. Further research should validate the proposed framework across different climatic regions and settlement conditions in South Africa.

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