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Modelling the impact of technological innovations on the sustainability of South African affordable housing projects

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Abstract

Sustainable, affordable house development can be facilitated by adopting appropriate technological innovations. However, limited studies provide practical knowledge on the impact of key influencers on adopting these technological innovations in African affordable housing projects. Therefore, the impact of internal and external influencers on the degree of technological innovation adaptation in South African affordable housing projects is examined in the current study. The initial findings were used to develop a sustainable, innovative, affordable housing (SIAH) causal model. The developed casual model and the relationship between the constructs/sub-constructs were validated through structured data collected from official South African home developers. The study found a low positive impact of internal influences and a moderate negative impact of external influences on home developers' adoption of technological innovation in South African affordable housing projects. Moreover, the research proved the high negative mediating impact of external influences on the association between internal influences and technological innovation adoption level. The study deduces that external influencers are the main drivers of adopting technological innovation in affordable housing, which means that by addressing the external influences, the level of adoption will significantly improve. This is due to the direct and mediating adverse effects of external influencers on adopting technological innovation in affordable housing projects. The SIAH model can be a robust framework to reduce the challenges of adaptation to technological innovations in SIAH.

Keywords

Affordable housing, Internal and external influences, Level of adoption, Sustainability, Technological innovation.

1. Introduction

Sustainability and innovation are positive changes in the construction industry, particularly the housing sector, due to alternative construction methods, sustainable materials, and new technologies (Moghayedi et al., 2021). Although a perception exists that innovation in construction projects, particularly affordable housing projects, is limited, improving productivity and quality, reducing cost and time of projects, and consequently, the sustainability of the project and meeting or exceeding projected goals often require innovation (Adabre et al., 2021). Sustainability practices and innovation within affordable housing projects provide the opportunity to not only reduce the cost and improve the quality of the housing but also enhance the environmental and social aspects of houses and therefore assist in developing sustainable, affordable housing, which is a competitive market, is a requirement for continued existence (Jamaludin et al., 2018). According to Moghayedi et al., (2022), a series of related events must occur in order for a sustainability practice or innovation to be successfully implemented; mere awareness of it does not guarantee adoption. Therefore, it is necessary to determine the critical internal factors influencing the adoption of sustainability and innovation in housing projects at both the project and company levels and external influencers. However, knowing which company and project factors are truly supportive requires a deep understanding of the process home designers and developers undertake in deciding to use sustainable methods and materials and new technologies in designing and constructing affordable housing projects. Knowing why, where and how home designers and developers adopt technological innovations and sustainability is crucial because it can expedite the diffusion rate of SIAH by facilitating their adoption. Therefore, it is necessary to research the internal and external factors that affect how technological innovations are adapted in affordable housing projects to provide a systematic overview to support

housing sectors and industry players in streamlining the process and, ideally, become more successful at utilizing the most appropriate alternative methods, sustainable materials, and new technologies to enhance the sustainability of affordable housing.

However, the role of technological innovations and their impacts on the sustainability of construction projects, particularly affordable housing, needs to be better understood. There is a clear need to rectify this. Moreover, current studies did not provide extensive quantitative analysis and understanding of the impact of critical internal and external influence factors on the level of adaptation of alternative methods, sustainable materials and new technologies in affordable housing projects in the global south. Several scholars emphasized this exciting gap and recommended a deep understanding of the impact of the key influential factors on sustainability and innovation in affordable housing projects (Moghayedi et al., 2021). Thus, this study aims to provide a deep understanding of the role of these influential factors in affordable housing projects by determining the nexus between the key internal and external drivers and level of adoption of technological innovations in affordable housing projects and how these factors and challenges impact on the level of adoption of sustainability and innovation in affordable housing projects.

2. Literature Review

The sustainable housing concept lacks urgency in the affordable housing sector. Most designers and developers do not demand it due to a lack of knowledge, which is not regulated by law (Adabre et al., 2021). The action for the SIAH concept is business-driven for some large developers. For many developers, profits are generated using conventional construction methods and materials to minimize the construction cost of housing regardless of the adverse effects it may cause on houses, which still dominate the sector (Moghayedi et al., 2022). Without considering the operating cost of developers in the housing industry, most developers tend to ignore the need for sustainability and innovation in the design and construction of affordable houses (Patel & Padhya, 2021). Adopting technological innovation in affordable housing creates an opportunity to enhance the sustainability of affordable housing (Moghayedi et al., 2021). Technological innovation is a robust source of innovation that can provide construction companies with new technologies that can adequately complement and transform existing technologies to create and sustain better performance. There are many types of innovations, and each one may apply to the building and particularly affordable housing sector. To significantly reduce the negative environmental impacts of buildings and improve the social and economic aspects, the adoption of sustainable design methods, alternative construction methods, natural materials and new technologies in the design, construction and operation of affordable houses are necessary (Moghayedi et al., 2021). Sustainability and innovation such as passive design, net-zero buildings, off-site construction, lean construction, renewable energy, water reuse, recycled materials and many more technological innovations have already been introduced to the construction industry. But the number of technological innovations used in affordable housing is still limited, and the sector significantly faces some challenges in adopting technological innovation (Jamaludin et al., 2018). According to Moghayedi et al. (2022), the level of adoption of technological innovations is a function of readiness and awareness for the innovation and enablers and barriers in adopting that technology.

Internal influencers refer to companies' and projects' characteristics that can encourage the adoption of technological innovations in housing projects. It can be divided into interest and commitment, policies and management, and resources and capability. Patel & Padhya, (2021) defined the influential internal factors as competency, commitment, and actions within construction organizations to adopt appropriate technological innovations to pursue sustainable projects. How sustainability and innovation are adopted in construction projects and what barriers and challenges impede sustainability and innovation processes are heavily related to the construction organizations' characteristics and project attributes (Banihashemi et al., 2017). Moghayedi et al. (2022) proved that knowledge about sustainability and technological innovations within construction companies enable the adoption of proper alternative methods, sustainable materials and new technologies in the projects. Moreover, advancing the adoption of sustainability and technological link to the climate and structure of a construction company and project (Banihashemi et al., 2017). Moghayedi et al. (2022) acknowledged the organizational characteristics such as the size of the company, establishment, expertise in a particular type of project, awareness and familiarity of company management and staff with sustainability and technological innovations as being essential to the level of adoption of technological innovation and sustainability in the construction projects. On the other hand, at the project level, Ozorhon and Oral (2017) determined that project attributes such as the project size, project type, project procurement and client of the project influence the adoption of technological innovation and sustainability in the construction projects. Moreover, contracting methods and procurement that legally and contractually form the project design and construction and encourage phase overlap contribute significantly to construction project sustainability and innovation (Naoum & Egbu, 2016).

Moreover, the awareness and familiarity of designers and home developers with relevant technological innovations and sustainability and innovation is an important factor in affecting the degree of success in the process and results of

sustainability and innovation in affordable housing projects (Adabre & Chan, 2020). Banihashemi et al. (2017) argued that project clients serve a vital role in construction projects' sustainable and innovative capacity. Akmam Syed Zakaria et al. (2018) stated that the size and type of project are major factors that affect the interest of many home designers and developers in sustainable, affordable projects by adopting more innovative methods, materials and technologies in the project. The sizes of the company also affect the capability to execute more innovative and sustainable practices in housing projects. Large construction firms can adopt more advanced and sustainable technological innovations because of their wide-range experience and skills, expertise, substantial capital, total commitment from leadership, and target projects and clients. Instead, small construction firms tend to keep costs to the minimum and adopting more technological innovations would invariably affect their profit margin (Akmam Syed Zakaria et al., 2018).

On the other hand, there are several barriers and challenges to adopting technological innovations as a sustainability catalyst in affordable housing projects in the global south, which are considered influential external factors. However, these challenges to innovation and sustainability exist at the project, company, and industry levels (Adabre et al., 2021). Policy and administrative barriers such as lack of regulation and policy and lack of incentive at the design and construction phases negatively affect the adaptation of technological innovations in housing projects (Kornilov et al., 2020). According to Moghayedi et al. (2022), limited home developers have the capability and interest to go beyond the lack of public or private incentives. Technological innovations pose a significant challenge for the construction industry, particularly the housing sector, due to the high cost of implementation, the difficulty of obtaining local technological innovations and sustainable materials and the lack of local technical skills to operate them (Patel & Padhya, 2021). Furthermore, Patel and Padhya (2021) identified the fear of upfront cost as the main reason for ignoring the implementation of technological innovations in affordable housing projects. Using alternative methods, sustainable materials, and new technologies requires new knowledge and skill. Therefore, a lack of technical knowledge and skills is a barrier to adopting technological innovations and, consequently, a failure to deliver sustainable buildings (Adabre & Chan, 2020). Since the technical knowledge and expertise of SME home developers in developing countries on technological innovations and sustainability are still low, they tend to appoint external experts, which adds to the overhead cost of projects (Pablo & London, 2020). Moghayedi et al. (2022) argued a need for local technological innovations in developing countries. As a result, it can be challenging to obtain alternative methods, sustainable materials and new technologies from the local market. The innovative building materials are mainly imported, leading to materials costs. Based on the abovementioned literature review, it is clear that project and company characteristics attributed as internal variables and challenges as external variables influence the adoption of technological innovations and sustainability in the affordable housing projects in the global south.

3. Research Design and Methodology

The study adopted a quantitative research design under a positivism philosophical approach to employ empirical methods, and makes extensive use of quantitative analysis to build a casual model for evaluating the effects of the project and company characteristics as internal influential and challenges as external influential variables on the level of adoption of sustainable design methods, alternative constriction methods, sustainable materials and new technologies by housing developers in the housing projects in South Africa. Based on the literature review, a causal model for adopting technological innovations in affordable housing was developed, as shown in Figure 1.

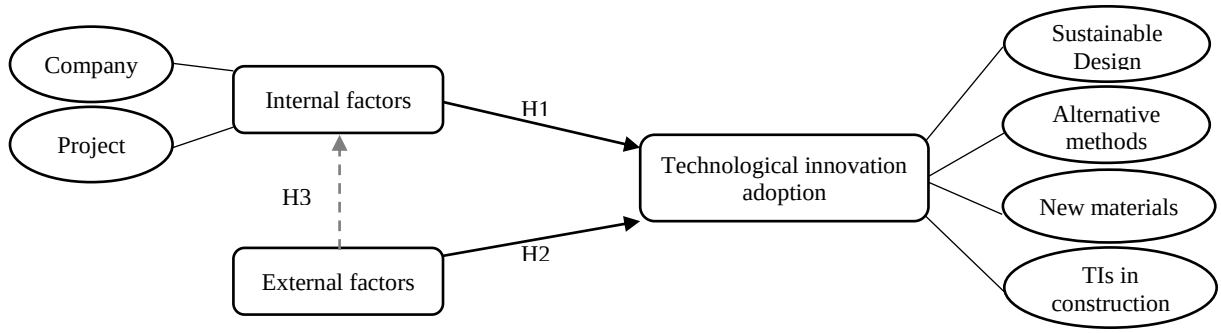
Based on the research objectives and developed casual model, the research is designed to test the following hypotheses:

- H1: Project and company characteristics as influential internal factors have a significant positive impact on the level of adoption of technological innovation in affordable housing projects
- H2: External influential factors have a significant negative impact on the level of adoption of technological innovation in affordable housing projects
- H3: External influential factors are negatively mediating the impact of influential internal factors on the level of adoption of technological innovation in affordable housing projects

A structured questionnaire survey was designed to gather the necessary data, and it was circulated using SurveyMonkey among the registered low-cost housing developers in South Africa. There were 517 valid responses collected across South Africa and used for data analysis. The questionnaire consisted of three following sections: 1. general information about home developer companies, 2. information on the level of adoption of technological innovations in previous affordable housing projects and 3. effect of internal and external influential factors on the level of adoption of sustainability and technological innovations in previous affordable housing projects using Likert scale. The collected data were analyzed using descriptive and inferential statistical techniques to develop the company profiles and level of adoption of technological innovations. Finally, the developed casual model was validated using

structural equation modelling (SEM) and the impact of influential factors on the adoption of technological innovations in affordable housing projects was quantified.

Fig. 1. Causal model of sustainable, innovative, affordable housing (SIAH)



3. 1 Research constructs and sub-constructs

The internal and external influential constructs and their sub-constructs and variables are listed in Table 1. Based on the literature review, the authors identified eight internal factors (company: 4, project: 4), ten variables for influential external factors, and 14, 9, 6 and 17 innovations for sustainable design, alternative methods, sustainable materials, and new technologies respectively as summarized in Table 1.

Table 1. Variables used in measuring the study constructs

Constructs	Sub Constructs	Variables	Source
Internal (I)	Company characteristics (C)	Company size (IC1), Relevant experience (IC2), Company establishment (IC3), Awareness and familiarity with sustainability and innovation (IC4)	1, 2, 3, 4, 5, 6
	Project characteristics (P)	Project size (IP1), Housing type (IP2), Project client (IP3), Project procurement (IP4)	1, 2, 3, 4, 5
External (E)		High cost (lifecycle) (E1), Lack of technical standards (E2), Incompatibility with other methods, materials or technologies (E3), Tendency to use conventional methods, materials and technologies (E4), Lack of public incentives (E5), Lack of technical skill and knowledge (E6), Lack of awareness of the availability (E7), Lack of policy and regulation (E8). Low social acceptance (E9). Low availability in the local market (E10)	6, 7, 8, 9
Innovations (I)	Sustainable design methods (D)	Passive design (ID1), Inclusive design (ID2), Cultural and heritage conservation design (ID3), Disaster resistance (ID4), Green building (ID5), Natural lighting (ID6), Natural ventilation (ID7), Passive thermal (ID8), Life-cycle cost (ID9), Life-cycle energy (ID10), Life-cycle carbon footprint (ID11), Water conservation (ID12), Renewable energy (ID13), Lean design (ID14)	6, 8, 9
	Alternative construction methods (A)	Water-efficient methods (IA1), Energy-efficient methods (IA2), Deconstruction/disassembly methods (IA3), Prefabrication (IA4), Modular (IA5), Construction waste management (IA6), Lean construction (IA7), Safe methods (IA8), Less labour intensive (IA9)	6, 7, 8, 9
	New building materials (M)	Natural materials (IM1), Local materials (IM2), Recycled materials (IM3), Green materials (IM4), Light materials (IM5), Nanomaterials (IM6)	6, 8, 9
	New technologies (T)	Computer-Aided Design (CAD) (IT1), Object-oriented Computer-aided design (IT2), Engineering design software (IT3), Artificial intelligence in design (IT4), Building Information modelling (IT5), Virtual Reality (IT6) Augmented Reality (IT7), Mixed Reality (IT8), Project portfolio management software (IT9), Laser scanner (IT10), Geographic Information System (IT11), Drone (IT12), Sensor (IT13), Wearable device (IT14), Tracking system (IT15), Special equipment or machine (IT16), 3D Printer (IT17)	8, 9, 10

1: (Banihashemi et al., 2017), 2: (Rahdari et al., 2016), 3: (Ozorhon & Oral, 2017), 4: (Naoum & Egbu, 2016), 5: (Akmam Syed Zakaria et al., 2018), 6:(Adabre et al., 2021), 7: (Kornilov et al., 2020), 8: (Patel & Padhya, 2021), 9: (Moghayedi et al., 2021), 10: (Li & Liu, 2019)

4. Results and Discussions

Table 2 summarized the characteristics of 517 home developers' companies participating in the current research and their housing project characteristics.

As indicated in Table 2, most home developers' size companies belong to small and micro with minimal experience in designing and constructing affordable housing, which is common across developing countries (Pablo and London, 2020). The project characteristics indicate the robust role of private developers in affordable housing projects since many affordable projects developed using traditional project delivery. However, integrating sustainability and innovation in projects, particularly in the construction stages, is significantly challenging due to the difficulty of amendment in this type of procurement by construction teams (Kavishe, Jefferson & Chileshe, 2019).

Table 2. Company and housing project characteristics

Company characteristics	Establishing	>20 years 12%, 11 - 20 Years 26%, 6 - 10 years 34%, < 5 years 28%
	Relevant experience	High 17%, Moderate 29%, Minimal 50%, No experience 4%
	Company size	Large 12%, Medium 18%, Small 39%, Micro 31%
	Awareness and familiarity with sustainability and innovation	High 25%, Moderate 40%, Minimal 24%, No familiarity 11%
Project characteristics	Project size	Large (more than 20units) 14%, Medium (11-20 units) 27%, Small (5-10 units) 34%, Very small (less than 5 units) 25%
	Project client	National government 15%, Local government 20%, Private 65%
	Housing type	Mixed 26%, Apartment 14%, Semi-detached 33%, Detached 27%
	Project procurement	Conventional 41%, Design and Build 27%, Management contracting 24%, Others 8%

The Relative Score was utilized to calculate the level of adoption of various methods, materials and technologies by developers in 517 samples size of affordable housing projects.

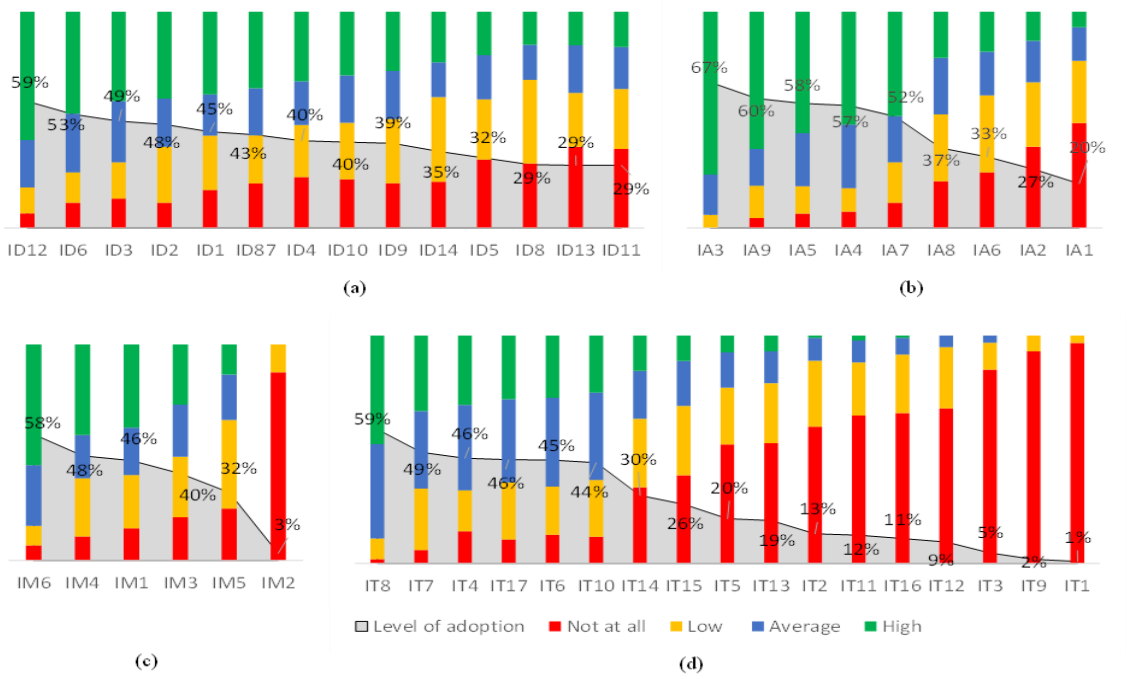


Fig. 2. Level of adoption of (a) sustainable design methods, (b) alternative construction methods, (c) sustainable materials and (d) new technologies

As shown in Figure 2 (a), most developers ignored sustainable design methods such as integrating renewable energy and life-cycle carbon footprint that affect the operation of houses to minimize the development cost of units. On the other hand, the results of alternative construction methods (b) disclosed that most developers adopted resources efficiency methods, which because of the increased consideration around the integration of environmental sustainability in the construction industry as well as the high price of energy and water in South Africa (Moghayedi

et al., 2021). Adopting sustainable materials (c) indicates that most developers use building materials available in the local market with lower transportation and hauling costs (Adabre & Chan, 2020). However, as shown in Figure 2 (d), the level of adoption of new technologies in South African affordable housing projects is relatively low. This finding aligns with the Patel and Padhya (2021) findings, which stated that technology adoption in housing projects in developing countries is considerably limited. This slow adoption may drive by the lack of knowledge and the high cost of these new technologies (Adabre et al., 2021). However, the high level of adoption of some technologies, such as drones, is due to developers' awareness of the potential advantages of drones in monitoring projects and the minimal cost and skill required for purchasing and operating a drone (Li & Liu, 2019).

4. 1 Causal Model of SIAH

Ultimately, to validate the developed casual model is tested using collected data from registered low-cost housing developers in South Africa. The internal consistency, composite reliability and convergent validity test results show good internal consistency between the variables under the same constructs ($0.7<\alpha<0.95$). Before analyzing the causality model, three hypotheses were tested using T-Statistics. P-Values of the hypotheses test are less than 0.05; therefore, all research hypotheses are statistically significant. Thus, the results of the research hypotheses tests validate the developed SIAH causal model of the study. Based on the hypotheses testing results, the study deduced that the influential internal factors (company and project characteristics) have a low positive (0.448) impact on adopting technological innovation in affordable housing projects. In contrast, the influential external factors have a moderate negative (-0.573) impact on the adoption of technological innovation in affordable housing projects. Furthermore, the indirect impact testing of the research hypotheses proves that the influential external factors negatively mediate the impact of influential internal factors on the adoption of technological innovation in affordable housing projects. Therefore, the total impact of influential internal factors was significantly reduced, as shown in the final causal model of SIAH in Figure 3.

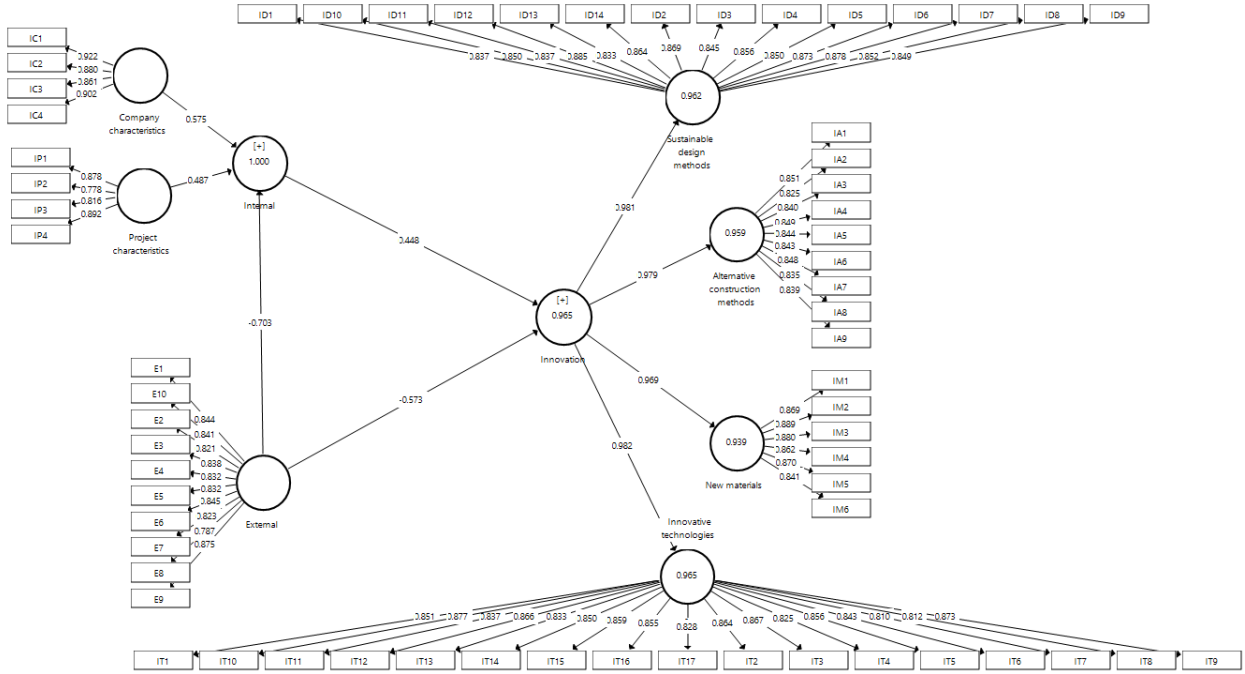


Fig. 3. Path analysis of the causal model of SIAH

As shown in Figure 3, sub-constructs and variables are highly linked to their relevant constructs (loading factors>0.8), proving a high nexus between variables and sub-constructs in the reflective measurement of constructs in the developed casual model. The positive associations among internal factors (company and project) and adoption of innovation of technological innovations in affordable housing projects directly depend on the company and project size, the relevant experience in affordable housing projects, technical staff awareness and familiarity with sustainability and innovation, housing types, project client and project procurement. The total effect coefficients model results also validated that the level of innovation adoption of technological innovations directly and indirectly (through internal factors) depends on ten identified external factors. However, comparing the level of impact of two constructs, internal (0.448) and influential external factors (-0.573), proved that the adoption of technological innovation and

sustainability in affordable housing projects are strongly associated with influential external factors. The external factors as a key drive predominantly hurdle to adopting technological innovation and sustainability through direct and indirect effects. Moreover, the path analysis diagram (Figure 3) shows the high negative impacts (-0.703) of external factors on the influence of internal factors on innovation adoption. Therefore, it can deduce that adopting innovation and sustainability in affordable housing projects will significantly improve by reducing the influential external factors. This is due to both the direct negative impacts of external factors on the adoption of technological innovations and the negative mediator impact of these factors on the association between influential internal factors on the level of adoption of technological innovation. These findings are aligned with previous scholars who acknowledge that the external factors (challenges) are the most influence on the level of adoption of innovation in construction projects and particularly housing projects (Jamaludin et al., 2018; Moghayedi et al., 2022; Patel & Padhya, 2021).

Lastly, the outer weights of dependent variables revealed that relevant experience (IC2), awareness and familiarity with sustainability and innovation (IC4), company size (IC1) and company establishment (IC3) are the most crucial company characteristics, respectively, whilst the housing type (IP2), project size (IP1), project client (IP3) and project procurement (IP4) are the most effective project characteristics. Considering the moderate negative impact of external factors, the variables under this construct influence the adoption of innovation and sustainability in affordable housing projects. As shown in Table 8, the high cost of methods and technology (E1) is the external variable with the most negative effect on adopting innovation and sustainability in affordable housing projects; this finding is supported by Adabre et al. (2021). Furthermore, low availability in the local market (E10), lack of incentives (E5), tendency to use conventional methods, materials or technologies (E4) and lack of technical knowledge (E6) are the other most predominant barriers that hurdle the adoption of innovation and sustainability, these findings verified by the study of Moghayedi et al. (2022) and Adabre et al. (2021). Overall, the Outer weights of variables of the two constructs are relatively close, which indicates the importance and effect of all selected variables on the adoption of innovation and sustainability in affordable housing projects.

5. Conclusions

The study investigates the influential internal and external factors and the level of adoption of innovation and sustainability in affordable housing projects in South Africa. The current research establishes the existence of causality and effects between these constructs. Furthermore, it validates their impact on the adoption of innovation and sustainability in affordable housing projects by empirically scrutinizing the relationship between internal and external variables and the adoption of technological innovations. The findings from the study have indicated that the adoption of innovation and sustainability in affordable housing projects is negatively associated with external variables and positively related to internal variables. Therefore, the adoption of sustainability and technological innovations in affordable housing should be increased to address current affordable housing issues and enhance the sustainability of housing and residents' quality of life. Hence, the awareness, opportunities and advantages for adopting innovation and sustainability in affordable housing must spread among all participants in affordable housing projects. Sustainability and innovation will disrupt affordable housing delivery and the business environment; hence, the housing stakeholders must adapt housing sectors to the changing dynamics. The study has contributed a framework for enhancing the sustainability and innovation in affordable housing as a cleaner production through integrating sustainable design methods, alternative construction methods, sustainable materials and new technologies in affordable housing projects and addressing the existing challenges.

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