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Developing a Framework for Innovation in House Construction: An Exploratory Study of Emerging Techniques and Practices †

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Abstract: Using innovation building technology in South Africa as case subjects, this study aims to explore the practices and techniques that are used in or as a part of the framework in innovation in house construction. This study explored the existing literature on the subject, followed by using the proposed framework. The study methodology, the proposed conceptual framework, was adopted from the house of quality and multicriteria decision making procedure. Data were collected in two stages and were used to test or validate the framework. The two stages of this study included a questionnaire survey that was targeted at end users, namely contractors of innovation building technologies in the house construction industry. The second stage was interviews targeted at the developers of innovation building technologies who are also referred to as system holders. Regarding the findings of the study, the proposed conceptual framework may be used to measure innovation in house construction and may be used hand in hand with existing South African regulations in the house construction industry. On the other hand, system holders may use the proposed conceptual framework as a guide in innovation building technology projects. The value of this study is in ensuring that innovation building technologies maintain their original advantages and survive the market.

Keywords: innovation building technology; conceptual framework; house construction industry; house of quality; multicriteria decision making

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1. Introduction

Innovation in house construction in South Africa is circumscribed to what is termed innovation building technologies (IBT), which the National Home Builders Regulations Council (NHBRC) defines as more inclusive of all innovation in artefacts or processes [1]. IBTs may be found in different fields of building construction, but this study is only focused on the house construction industry in South Africa. The Housing Consumers Protection Measures Act of 1998 (No. 95 of 1998) [2] relates IBTs as non-standardised construction, which is defined as any form of building that utilises building systems, methods, materials, elements or components which are not fully covered by existing standards and specifications or codes of practice and/ or which are not described or referred to in "deemed-to-satisfy" rules of National Building Regulations [1]. In some instances, IBTs may be compared with standard building systems, which include building systems, methods, materials, elements, or components that are fully covered by existing South African standards and specifications or codes of practices.

In this study, practice is referred to as the actual application of theories, regulations on construction methods, or materials both in design, manufacturing, and construction. The code of practice, called 'The Application of the National Building Regulations', SANS 10400, covers the provisions for building site operations and building design and construction that are deemed to satisfy the provisions of the National Building Regulations [3]. On the other hand, the technique is referred to as the skill to execute both standardised and non-standardised practices in accordance with the National Building Regulations. This study is an exploration of the non-standardised practices as well as the techniques applicable to such practices. It further investigates the existing frameworks and then proposes a new framework for innovation in house construction. The existing framework in South Africa is performance-based and incorporates the voice and decisions of the engineers. The proposed framework is also performance-based but incorporates both the voice of the engineers as well as the voice of the end user or customer of the IBT systems and products. The significance of the research is in improving the existing framework regarding IBTs and providing directions for future research. The material covered in this paper forms part of one of the authors' doctoral studies, and some will be included in a future publication.

2. Research Methods

A qualitative approach was followed in this research. The study methodology, the proposed conceptual framework, was adopted from two proven theories, which are the house of quality and the multicriteria decision making (MCDM) procedure [4–6]. The house of quality was used in the overall design of the proposed framework, whilst the multicriteria decision making procedure, incorporating the analytic hierarchy process (AHP) [6], was used to determine the weights of the customer attributes or voice of the customers [4].

Data were collected in two stages, which included a questionnaire survey that was targeted at customers such as the end users or contractors of IBTs in the house construction industry, and then unstructured interviews targeted at system holders or engineers. The survey requested the customer to rate their needs regarding IBT systems or products, rating them on a Likert scale from 1 to 5, where 1 and 5 represented the least important need and the most important need, respectively [7]. The questionnaire survey results were used as a guide to pair the items of the matrix as closely as possible to customers' needs. The needs of customers are referred to customer attributes (CAs), whilst the system holders' or engineers' design dimensions are called engineering characteristics (ECs) in this paper. The second stage included interviews targeted at the developers of IBTs or system holders, where each participant was asked a question regarding customer satisfaction. The results were recorded and are presented in the next section of this paper. Figure 1 shows the summary of the research methods, in which Part 1 is the qualitative data collection process and the review of the literature regarding the existing framework. Then, Part 2 involves the design of the proposed framework incorporating the existing framework. Part 3 covers case studies that the framework was tested on and does not form part of this paper.

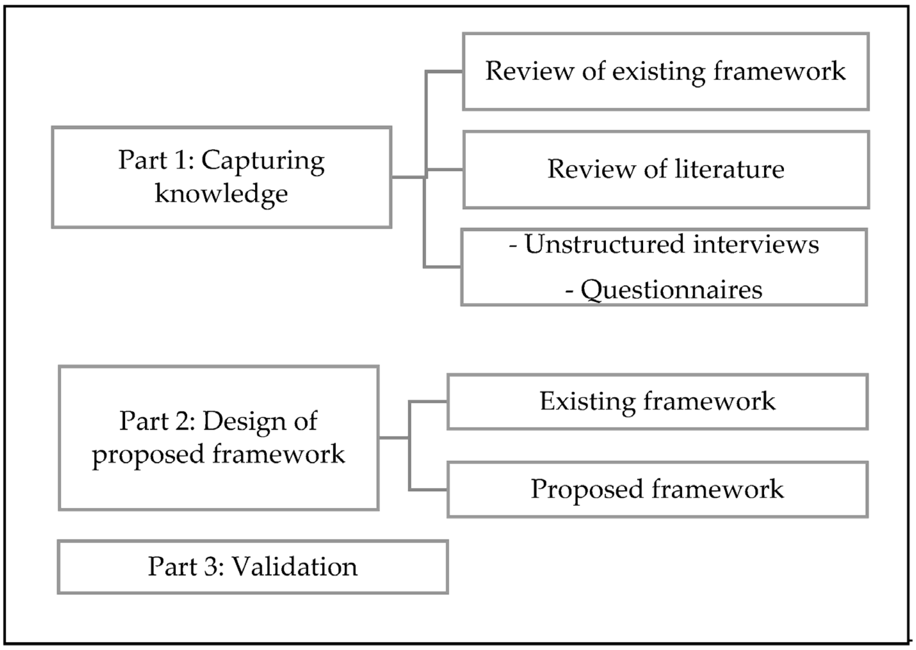

Figure 1. Summary of research methods.

3. Results

This section presents the results of the survey questionnaires, unstructured interviews, the existing framework, as well as the design of the proposed framework.

3.1. Qualitative Results

The results from the questionnaire survey were analyzed using the AHP (See Appendix A) and are presented in Table 1. The priority index may be seen as a measure of importance or priority amongst the given concepts [4].

Table 1. Results of AHP and MCDM for CAs.

Customer Attributes (CAs)	Priority Index
Structural Integrity	0.541
Durability	0.272
Habitability	0.076
Sustainability	0.075
Ease	0.036
	$\sum = 1$

The IBT developers, system holders, and engineers were asked the following question during an unstructured interview: 'What do you see as the most important design dimension in your system or product, that will satisfy your customer the most?'. The results were recorded and are presented in Table 2, where 'x' represent an agreement:

Table 2. Results from the interviews.

Design Dimensions	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5	Participant 6
Generating strength	x	x	x			
Generating stability		x	x	x		
Protect against water		x		x		x
Protect against fire		x		x	x	
Ensuring sustainability		x				x

3.2. Existing Framework

The existing framework for the National Building Regulations is a four-level framework and stands on two legs. The first leg comprises compliance methods with standards or codes, which are the application of the ‘deemed to satisfy’ design and construction rules. The second leg comprises performance-based methods, which are the application of the rational assessment, rational designs, and certification for non-standardized practices, namely IBTs. The framework shown in Figure 2 does not show where customer attributes or services are incorporated.

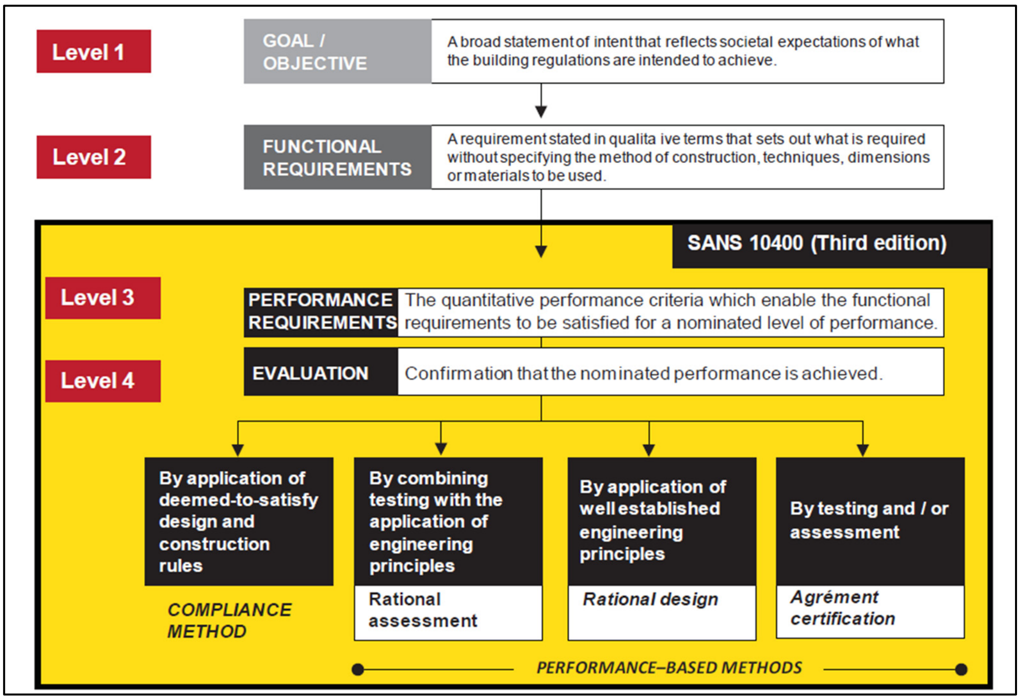

Figure 2. The existing framework for the National Building Regulations [8].

3.3. Proposed Framework

The proposed framework incorporates both engineering characteristics (ECs) as well as customer attributes (CAs). The framework is for non-standardized practices, IBTs, and covers all the first four design dimensions (strength, stability, water protection, and fire protection) that are in the performance-based framework but includes sustainability as the new proposed design dimension. The design dimensions (strength, stability, water protection, fire protection, and sustainability) were measured in terms of deformation (m), degree of compatibility (%), saturation ($\ell/m^2/s$), fire resistance in (s), and carbon footprint (m^2), respectively; see Figure 3.

When observing Figure 3, it can be seen that the vertical parts of the proposed framework are all about engineers’ voices and the design dimensions, whilst the horizontal parts are all about customers’ voices. Where the vertical and horizontal parts meet, the relationship matrix between engineers’ voices and customers’ voices is created. The details of the relationship matrix are further demonstrated in the case studies which are not part of this paper. Figure 3 further shows that incorporating customers’ voices or attributes will lead to the competition plan for the IBT system or product. The other important aspects from Figure 3 are the CA and EC correlation matrices, which are meant to establish the co-relationships between the CAs themselves as well as the co-relationships between the ECs themselves. The AC and EC relationships will be analyzed using factor analysis in the form of case studies in a future research paper.

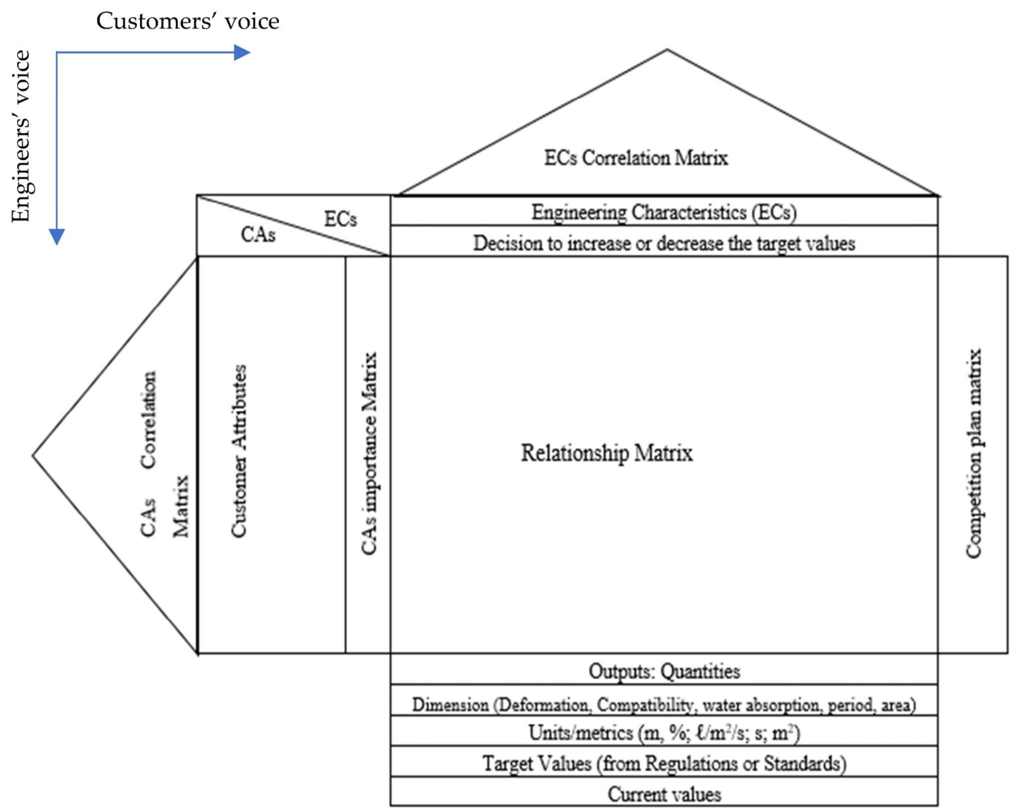

Figure 3. The proposed framework.

4. Discussion

The results of the questionnaire survey were analyzed using the AHP and are presented in Table 1. The results from the questionnaires showed that the most important attribute to customers was the structural integrity of the IBT system or product. The second most important attribute was durability, followed by habitability and sustainability, and the least important was the ease of erection or installation of the IBT system or product. Factors that affect the rating of customer attributes may be associated with safety and security, hence the structural integrity of the system or product was rated the most important. Other factors may be the techniques used, which may have contributed to the least important rating for the ease of erection. It is also possible that the customer may rather opt for manufactures or system holders to assist in the installation or erection of the system.

The results from the unstructured interviews included those from six participants, and the results are shown in Table 2. The four design dimensions that the system holders and engineers perceive to satisfy their customers the most were (1) generating strength, (2) generating stability, (3) protection against water, and (4) protection against fire. It should be noted that other factors that may influence the decision of the system holders and engineers such as cost of production, profit, and policies were not considered in the interviews. One may think that sustainability and environmental laws may be important to the system holders but not to the customers. It is also vital to note that the techniques for incorporating environmental aspects and sustainability in the other design dimensions have become a need for most system holders and engineers.

The results presented in Table 1 can be incorporated in the proposed framework under the CA importance matrix in Figure 3. On the other hand, the results from Table 2 may be incorporated at the bottom of the framework (Figure 3), to guide the system holders or engineers with their targets. Results from Table 1 will also be utilized to establish the relation matrix between the CAs and ECs. Hence, Tables 1 and 2 are the main inputs to the proposed framework.

5. Conclusions

Although this is ongoing research, the main finding is that the existing National Building Regulations framework for non-standardized practices can be strengthened by incorporating customers' voices into the design aspects.

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Appendix A. AHP on Customer Attributes

Appendix A.1. Initial Assumptions

The customer attributes were initially assumed to be represented by the numbers:
1 = Structural Integrity
2 = Durability
3 = Habitability
4 = Sustainability
5 = Ease

Appendix A.2. Pairwise Matrix

To start the process, the rows and columns of the matrix were populated with numbers ranging from 1 to 9, and the decisions on rating the pairs was guided by the responses of the questionnaires, as shown in Table A1 below:

Table A1. Pairwise matrix of customer attributes.

	1	**2**	**3**	**4**	**5**
1	1.0000	5.0000	7.0000	7.0000	9.0000
2	0.2000	1.0000	5.0000	7.0000	7.0000
3	0.1429	0.2000	1.0000	1.0000	3.0000
4	0.1429	0.1429	1.0000	1.0000	3.0000
5	0.1111	0.1429	0.3333	0.3333	1.0000
$\sum$	**1.5968**	**6.4857**	**14.3333**	**16.3333**	**23.0000**

Appendix A.3. Row Average Operation Matrix

The pairwise was followed by the row average operation matrix in to order to obtain the priority indices as shown in Table A2 below:

Table A2. Priority index operation matrix.

	1	2	3	4	5	Priority Index
1	0.6262	0.7709	0.4884	0.4286	0.3913	**0.5411**
2	0.1252	0.1542	0.3488	0.4286	0.3043	**0.2722**
3	0.0895	0.0308	0.0698	0.0612	0.1304	**0.0763**
4	0.0895	0.0220	0.0698	0.0612	0.1304	**0.0746**
5	0.0696	0.0220	0.0233	0.0204	0.0435	**0.0358**
						1.0000

Appendix A.4. Consistency Operation Matrix

The consistency of the calculation and judgement based on the questionnaire responses was validated by the consistency operation matrix, shown below:

Table A3. Consistency operation matrix.

	1	2	3	4	5	A = ∑	A/Priority Index
1	0.5411	1.3612	0.5344	0.5221	0.3218	**3.2805**	**6.0629**
2	0.1082	0.2722	0.3817	0.5221	0.2503	**1.5345**	**5.6367**
3	0.0773	0.0544	0.0763	0.0746	0.1073	**0.3899**	**5.1074**
4	0.0773	0.0389	0.0763	0.0746	0.1073	**0.3744**	**5.0195**
5	0.0601	0.0389	0.0254	0.0249	0.0358	**0.1851**	**5.1768**
						1.1529	**5.4006**

The following equations were used:

$$\begin{aligned}&\text{Consistency index, CI} = (\text{L} - \text{N})/(\text{n} - 1)\\&\text{where L} = 5.4006 \text{ (average of all priority indexes);}\\&\text{N} = \text{n} = \text{size of the pairwise matrix}\\&\text{The Consistency Ratio, CR} = {}^{\text{CI}}/\text{RI}\\&\quad\text{where Random Index, RI} = 1.12\end{aligned}$$

The validation or conformance was reached when, CR $\leq$ 0.1.
Consistency index, CI = 0.1002
Consistency ratio, CR = 0.0894
The random index was obtained from literature as published by Saaty, 1980 [6]:

Table A4. Random consistency indices [6].

Matrix Size	Random Consistency Index
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

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