Dwellers' Perception of Choosing 3D-Printed Residential Units Over Conventional in the UAE: A Structural Equation Modeling Approach

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Abstract

Three Dimensional printed residential houses are created with substantial 3D printers with the ability to extrude the building materials through nozzles which eventually build a 3D object at the size and dimension of a residential unit. Unlike the traditional methods of building houses, 3D Printing units consumes less energy in constructing residential units. The construction of these units is energy efficient as it uses low-energy technology that encourages energy sparingly. In the Middle East, the United Arab Emirates has made immense efforts in implementing 3D technologies. The aim of this research is to measure and define the main factors that affect dweller's perception on the 3D printing residential units' adoption. To do so, structural equation modeling was used to measure dwellers' perception and their commitment through selected factor. The selected factors are grouped into four categories which are environmental, social, economic and technological. The main factors that impacted the dwellers' perception includes waste reduction, access to amenities and recreational areas, cost-effective and design customization. Towards perception of selecting 3D printed houses and commitment towards sustainability the results showed a positive impact. The practical implication of the study will aid the construction sector in the decision-making process of 3D printed units implementation.

Keywords

3D Printing, 3D Units, Sustainability, Construction, Dwellers, Residential, SEM, UAE.

1. Introduction

The construction industry is known to be one of the most industries that consumes vast amount of resources and having substantial environmental stresses. It is responsible for nearly 38% of Green House Gases (GHG) emissions, 40% of solid waste, and 12% of potable water (Khan et al., 2021). Moreover, it has been reported by (Klotz et al., 2007) that buildings have consumed 36% of the total energy used, 30% of the raw material used and 12% of potable water consumed in the U.S. Its trail and impact are expected to increase given the fact that urban population is anticipated to represent 68% of the world's total dwellers by 2050 which means more built environment projects, more construction and more usage of concrete (Khan et al., 2021). As a consequence it will have a massive economic, social and environmental impact on the globe, ecological systems, and people concerning housing, transportation and different infrastructure necessities (Khan et al., 2021). Therefore, more efficient, sustainable, and innovative technologies must be established, adopted and applied by the construction industry to meet the needs of the build environment and economic and social circumstances. Such technologies are Building Information technologies (BIM), Automation in Construction, and 3D printing.

3D printing is considered an innovative technology that support the triple bottom line; people, profit and planet and is the main focus of this research. The 3D printing was introduced in 1983 by Charles W. Hull, it is a process by which physical objects are created by adding materials in layers based on a digital model. 3D printing technology in the construction is used in many areas such as in producing construction parts, in architectural models and building projects. 3D printing can bring substantial changes to the construction industry, not only as a methodology but also in terms of productivity improvement. Such productivity improvements are (1) waste reduction, (2) flexibility in design that give the developers flexibility in designing structures that can't be done using manual construction practice, (3) less manpower since it is an automated process and other environmental, economic and constructability-related improvements (Wu et al., 2016).

2. Literature Review

2.1 3D-printing as a sustainable approach

3D printing technology is an approach to fulfill the demand for more sustainable and resource-efficient concrete construction practices. It is an approach that aid in improving carbon footprints of buildings by lessening their embodies and operating energy (Khan et al., 2021). Moreover, it helps to attain improved time and cost management, enabling lean construction, and support sustainability in the building sector (OZTURK, 2018) (Mahadevan et al., 2020). 3D printing is also considered sustainable in terms of material usage, it is an additive approach rather than subtractive, hence less materials are required when compared to traditional processes. The required materials are only placed therefore will save on material consumption, that will provide an optimization of the construction components and reduce the industry's environmental impact (Pessoa et al., 2021). This is because when less waste is produced consequently the CO_2 footprint is reduced (Pessoa et al., 2021).

3D printing will make construction more efficient while creating sustainable growth and motivating circularity principles, for example through the usage of recycled and environmentally friendly materials unlike most of the conventional approaches that are unsustainable (Despeisse et al., 2017). This will create new opportunities for employment in construction companies that utilize the use of 3D printing systems in their projects. From an economical point of view, this technology is regarded as a cost effective approach in constructing buildings (Khan et al., 2021). As demonstrated, 3D printing technology tackles the three pillars of sustainability, i.e., economic, environment and social, therefore considered a sustainable approach.

2.2 Dwellers' factors for choosing residential units.

There are numerous factors that gives credit to choosing 3D-printing units over conventional, and these factors can include environmental, economic, technological, and social. From an environmental aspect, as known 3D structures are fabricated directly from a digital model in consecutive layers with less materials, which means it minimizes waste of the costly metals. Besides, the fabricated structure can be recycled once they have reached the end of their useful life leading to reduction in waste consequently having less environmental impact. Another way the 3D printing will result in less waste is that its automated system will lessen the impact of human error on the building process thus waste reduction (Holt et al., 2019; Nematollahi et al., 2017). Related to the environment also, 3D printed units contributes to sustainability through reduction in carbon emission (Abdalla et al., 2021). Moreover, 3D printing processes have been coupled with a cost-effective fabrication process that reduce the energy use, resource demand and CO_2 emission (De Schutter et al., 2018). Furthermore, it is reported that 3D printed units enhance the thermal comfort within the building and improves the air quality (De Longueville et al., 2020; Mahadevan et al., 2020).

From a social aspect, socio-economic and socio-demographics are main categories that affect the residential unit buyers when they are searching for units when relocating which suits their needs (Petkar & Macwan, 2018). 3D printing promises several benefits from a social point of view where it creates new jobs and improved productivity and performance in the construction industry (Aghimien et al., 2020; Frearson, 2018). Moreover, 3D printed units when fabricated at site poses less injuries and fatalities compared to conventional construction as reported by (Hager et al., 2016; Madiwale). Even in affordability, 3D units are more affordable compared to units built conventionally (Lojanica et al., 2018).

3D printing technology is economical in terms of cost, materials, and labor reduction, which achieves strong affordability, and environmental in terms of friendly local material usage, which will consequently achieve health aspects with fast achievement and efficiency in the fabrication process (Lojanica et al., 2018). Therefore, it can be emphasized that dweller's perception is an important aspect for the developers to develop residential projects capable of catering the most out of the land while maintaining the required needs and as such the 3-D printed households require those attributes to attract dwellers into accepting such technology. It was found that there are four main dimensions that are correlated to such perceptions. These dimensions are summarized in table 1 below, along with the relevant references from the literature:

Table 1: 3D printing units factors that affects dwellers' perception

Category	***Factors***	***References***
Environment	Waste reduction	(Holt et al., 2019; Nematollahi et al., 2017) (Aghimien et al., 2020; Cole & Baghi, 2022; Siddika et al., 2020),(Petrovic et al., 2011);(Weinstein & Nawara, 2015);(Allouzi et al., 2020), (Elantary et al., 2021);(Madiwale)
	Reduction in carbon emission	(Abdalla et al., 2021; Alkhalidi & Hatuqay, 2020; De Schutter et al., 2018; Khan et al., 2021; Liu et al., 2016; Mahadevan et al., 2020; Puppos, 2021; Schuldt et al., 2021); (Holt et al., 2019);(Wu et al., 2016);(Koslow, 2017);(Sakin & Kiroglu, 2017);(De Longueville et al., 2020);(Elantary et al., 2021)
	Reduction in energy consumption	(He et al., 2020; Puppos, 2021) (Cole & Baghi, 2022; De Schutter et al., 2018; Liu et al., 2016; Mahadevan et al., 2020; Schuldt et al., 2021);(De Longueville et al., 2020)
	Thermal comfort	(He et al., 2020; Mahadevan et al., 2020);(Cui et al., 2022)
	Air Quality	(De Longueville et al., 2020)
	Initiative government support	(Kuan & Chau, 2001);(Lian et al., 2014);(Weller et al., 2015);(Yeh & Chen, 2018);(Mavri et al., 2021)
	Green infrastructure	(De Longueville et al., 2020)
Social	New job creation	(Aghimien et al., 2020; Fonseca, 2018)
	Access to social interaction with neighbors	(Petkar & Macwan, 2018); (Li & Wu, 2013);(Mohd Thas Thaker & Chandra Sakaran, 2016);(Cerin et al., 2013);(Nejad et al., 2021)
	Access to Amenities and recreational locations	(Petkar & Macwan, 2018); (Li & Wu, 2013);(Mohd Thas Thaker & Chandra Sakaran, 2016);(Cerin et al., 2013);(Nejad et al., 2021)
	Security & Privacy	(Ballard, 2005); (Othman et al., 2015);(Cerin et al., 2013)
	Less injuries and fatalities	(Aghimien et al., 2020; Hager et al., 2016; Madiwale; Sakin & Kiroglu, 2017)
	Social Awareness	(Ballard, 2005); (Othman et al., 2015);(Cerin et al., 2013) (Hager et al., 2016; Madiwale; Sakin & Kiroglu, 2017)
Economic	Cost-effective	(Holt et al., 2019) (De Jong & De Bruijn, 2013; Koslow, 2017; Mpofu et al., 2014; Sakin & Kiroglu, 2017) (Mahachi, 2021) (Abdalla et al., 2021; De Schutter et al., 2018; Puppos, 2021; Siddika et al., 2020; Wu et al., 2016); (Sakin & Kiroglu, 2017; Tobi et al., 2018)
	Transportability	(Aghimien et al., 2020; Holt et al., 2019); (Puppos, 2021); (Oberti & Plantamura, 2015; Sakin & Kiroglu, 2017);(Petkar & Macwan, 2018); (Li & Wu, 2013);(Mohd Thas Thaker & Chandra Sakaran, 2016);(Sakin & Kiroglu, 2017)

	Affordability of unit price	(Petkar & Macwan, 2018); (Li & Wu, 2013);(Mohd Thas Thaker & Chandra Sakaran, 2016);(Cerin et al., 2013);(Nejad et al., 2021), (Aghimien et al., 2020; Lojanica et al., 2018) (Mahdi, 2021) (Humaidan et al., 2019) (Coblentz, 2019) (Puppos, 2021)
Technological	Time to complete	(Holt et al., 2019; Mpofu et al., 2014) (Koslow, 2017) (Nematollahi et al., 2017) (De Schutter et al., 2018; Fonseca, 2018) (Cole & Baghi, 2022; Siddika et al., 2020),(Sakin & Kiroglu, 2017)
	Design Customization	(Holt et al., 2019) (Sakin & Kiroglu, 2017) (Mahachi, 2021) (De Schutter et al., 2018; Wu et al., 2016) (Sakin & Kiroglu, 2017; Tay et al., 2017)
	Structural integrity	(Roodman et al., 1995),(Allouzi et al., 2020; Zareiyan & Khoshnevis, 2017),(Tay et al., 2019),(Sakin & Kiroglu, 2017)
	convenient maintenance	(Sakin & Kiroglu, 2017)

3. Methodology

3.1 Geographical location and Data Collection

The research was done in the United Arab Emirates (UAE) and targeted all its residents, UAE citizens and expatriates in all seven emirates. The research methodology was done using SEM. In order to know the dwellers' perception of choosing 3D-printed residential units over conventional ones, a structural equation modelling approach was done. Based on the literature review, 20 factors were found related to the 3D printed units for SEM. The primary phase of the research was a comprehensive literature review, and the secondary phase was obtained through questionnaires. For validation purpose, the questionnaire was piloted, then were refined based on the subject matter experts (SMEs) along with people from different backgrounds to ensure that all questions reflected all dimensions. Moreover, the questionnaire began by introducing the topic of 3D printing units to familiarize the respondents who don't have any previous knowledge about the topic. To do the former, a questionnaire was prepared to measure every factor under each dimension using questionnaire. In the questionnaire, each factor is represented by one question using 5-point Likert scale (1: strongly disagree, 2: disagree, 3: neutral, 4: agree, and 5: strongly agree).

3.2 Data Analysis

The data analysis is divided into three steps, (1) data validation, (2) Confirmatory Factor Analysis (CFA), (3) Structure Equation Modelling (SEM). The following subsection will further elaborate each step.

3.2.1 Data Validation

To test the reliability and the validity of the collected data, the internal consistency of each dimension was measured. The data collected from the questionnaire was validated through assessing the internal consistency of the responses using Cronbach's $\propto$ to measure how each factor is related to one another within the same dimension using Composite Reliability (CR).

3.2.2 Confirmatory Factor Analysis

The role of confirmatory factor analysis is to do a test on findings and arguments to determine their validity using the most common statistical tools, that is, confidence, interference, and significance (Harrington, 2009). To test our measurement model, the standardized covariance matrix of the selected dimensions is analyzed to test the following hypothesis.

3.2.3 Structural Equation Modeling

Structural equation modeling is a statistical tool that is used to analyze structural relationships using multivariate options. This model uses a combination of multiple regression analysis and factor analysis, using them simultaneously to measure latent constructs and measured variables (Kim & Jung, 2016). This research was conducted through SEM, where factors was gathered from literature review and then gathered under four endogenous dimensions which are (1) environment, (2) social, (3) economic, and (4) technology. A Confirmatory Factor Analysis (CFA) was conducted to measure the dimensions using the extracted factors from literature review as explained in the above sub-section followed by SEM to assess the impact of the endogenous dimensions on the dwellers' perception which is the exogenous dimension. To test our hypothetical model, the standardized covariance matrix of all selected dimensions and their factors are analyzed to test the following hypotheses:

H1: There is a significant correlation among the tested dimensions.

H2: Environmental aspect has positive impact on dwellers' perception of choosing 3D-printed residential units over conventional ones.

H3: Social aspect has positive impact on dwellers' perception of choosing 3D-printed residential units over conventional ones.

H4: Economic aspect has positive impact on dwellers' perception of choosing 3D-printed residential units over conventional ones.

H5: Technological aspect has positive impact on dwellers' perception of choosing 3D-printed residential units over conventional ones.

H6: There is a significant correlation between the tested dimensions with the presence of the perception model.

H7: There is a significant impact of the dwellers' perception on their commitment towards sustainability.

4. Results and Discussion

4.1 Results

4.1.1 Demographics

At the data collection stage, the data collected from population of UAE and a sample of 250 respondents answered the distributed survey. The gender distribution was 70% females and 30% males which would provide better understanding as females are mostly utilizing their household units. The age ranges had a lot of variations but mostly were in the range of 25-30 years as approx. 50% of the respondents whereas 18-24 and 31-40 years got approx. 23% and 20% respectively whereas above 40 years old were 6%. In terms of the marital status, it was found that 60% were singles and 37.2% married and 2.8% divorced. For the married couples, the question had to be on the number of occupants in the household and it was observed that 3-5 people got approx. 40% whereas 2 persons had 23%, 6-7 people and above 7 had 19% and 15% respectively. The level of academic education had bachelor's holders of 52.23%, Master's degree with 31.25% whereas the High School diploma holders got 10.71% and PhD degree with 5.80%. Next was the employment status which got approximately 70% full employment, 21% seeking jobs, 5.36% part-time employed and 3.57% retired. The monthly salary was asked later with 43% for more than 20,000 AED, 5,000-10,000 AED got 20%, 11,000-20,000 AED obtained 18% and less than 5,000 AED got 17%. Finally, the nationality of the respondents were 43.30% Emiratis and 56.70% non-Emiratis.

4.1.2 Data Validation Results

The validity and reliability measures for the data collected are shown in table 2 without the exclusion of any insignificant dimensions as the SEM has shown higher reliability from the first run while checking the Cronbach's ∝ value for each dimension. It was noticed from the below table 2 that Cronbach's ∝ and CR values are all above 0.75 whereas the common minimum statistical value for this measurement is 0.7 therefore all the dimensions can remain in the model without exclusion as mentioned earlier.

Table 2: Data validation and CFA estimates.

Dimension	***Codes***	***Correlation with Total***	***Cronbach's ∝***	***CR***	***CFA Standardized Parameter Estimates***	***CFA Standardized Parameter Estimates P-value***
Environmental			**0.813**	**0.810**		
Waste reduction	EWR	0.573			0.6535	<.0001
Reduction in carbon emission	ECE	0.571			0.57617	<.0001
Reduction in energy consumption	EEC	0.527			0.76191	<.0001
Thermal comfort	ETC	0.617			0.58479	<.0001
Air Quality	EAQ	0.484			0.63604	<.0001
Initiative government support	EGS	0.557			0.58346	<.0001
Green infrastructure	EGI	0.521			0.62068	<.0001
Social			**0.819**	**0.813**		
New job creation	SJC	0.509			0.55488	<.0001
Access to social interaction with neighbors	SSI	0.588			0.59487	<.0001
Access to Amenities and recreational locations	SAR	0.645			0.71988	<.0001
Security & Privacy	SSP	0.578			0.66851	<.0001
Less injuries and fatalities	SIF	0.599			0.68659	<.0001
Social Awareness	SSA	0.585			0.67237	<.0001
Economic			**0.765**	**0.766**		
Cost-effective	CCE	0.632			0.78031	<.0001
Transportability	CCT	0.558			0.78178	<.0001
Affordability of unit price	CUP	0.604			0.78278	<.0001
Technology			**0.787**	**0.788**		

Time to complete.	TTC	0.608	0.73324	<.0001
Design Customization	TDC	0.659	0.73062	<.0001
Structural integrity	TSI	0.553	0.63926	<.0001
Convenient maintenance	TCM	0.562	0.65392	<.0001

4.1.3 CFA Results

The CFA results are shown in table 2 where it illustrates that the CFA standardized parameter estimates (loadings) are below 0.7, however, since the values are near or around 0.5, this would be included in this SEM model. Although, some factors are less than 0.5 yet the p-value for each of those factors is nearing 0 thus indicates significance to the SEM model. Furthermore, table 3 illustrates the CFA goodness of fit criteria of the model where it shows that the Standardized Root Mean Square Error is 0.0529 which is lower than the acceptable minimum value of 0.06. Next, the Goodness of Fit Index (GFI) showed a value of 0.8870, Adjusted GFI (AGFI) 0.7504 and Bentler Comparative Fit Index was 0.9145 which are all above 0.80 which supports our earlier conclusion of being significant and relatable to the CFA model. In addition to the CFA model, SAS had generated table 4 which is the CFA-Covariance Matrix Among the criteria. This table illustrates that there is a high correlation between the dimensions through the covariance estimates and the p-value that are <0.001. Therefore, this table 5 is a great associate that proves our hypothesis (H1: There is a significant correlation among the tested dimensions). Moreover, when SEM model was tested the correlation even improved as shown in table 6.

Table 3: CFA goodness of fit criteria.

Criteria	Value
Standardized Root Mean Square Error (SRMSR)	0.0529
Goodness of Fit Index (GFI)	0.8870
Adjusted GFI (AGFI)	0.7504
Bentler Comparative Fit Index	0.9145

Table 4: CFA - Covariance Matrix among the criteria

	Environment	**Social**	**Economy**	**Technology**
Environment		1.02437 <0.001	0.45625 <0.001	0.87535 <0.001
Social			0.59491 <0.001	0.84178 <0.001
Economy				0.65664 <0.001
Technology				

4.1.4 SEM Results

Through the SEM modeling, it was assumed through the literature review that the sustainable dimensions of environmental, social, economic, and technological have a positive correlation with the dweller's perspective to choose 3D printed households. Based on the hypotheses tested which was adopted from the literature review, the initial SEM model was built as shown in figure 2. All factors selected at the beginning was retained in the model and nothing was excluded, therefore the initial model is the final one. In addition, figure 3 illustrates the SEM model that tested H7 (There is a significant impact of the dwellers' perception on their commitment towards sustainability). The goodness of fit for the SEM is shown below in table 5 as the Standardized SRMSR is 0. 0.0546 which is less than the minimal statistical value of 0.06. At the same time, the goodness of fit (GFI) 0.903, Adjusted GFI (AGFI) 0.7938 and

Bentler Comparative Fit Index 0.914 are all above 0.8 which indicates that the model is complying with our literature findings and the data collected from the questionnaire.

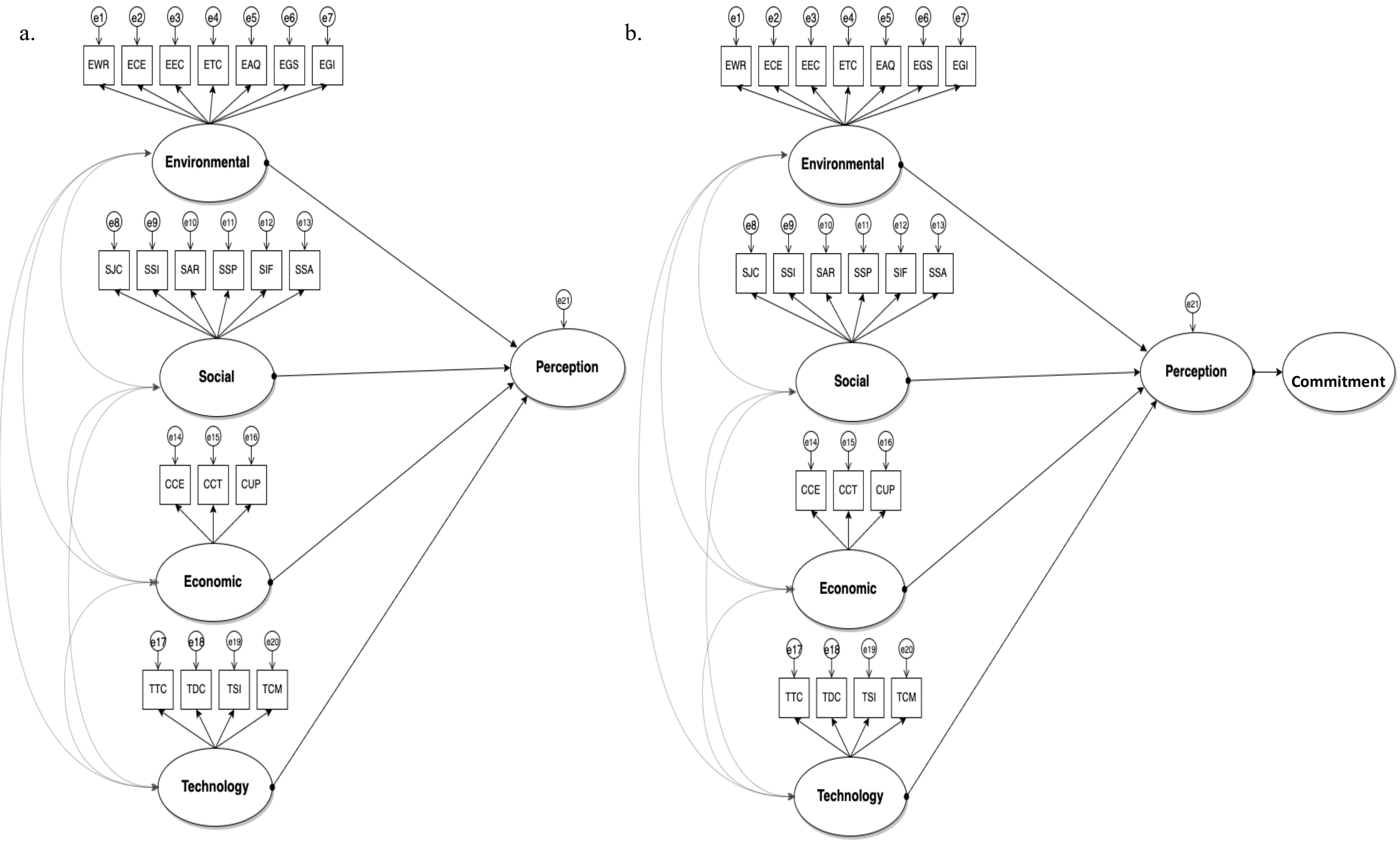

Figure 1: (a) Illustrates the initial SEM model and (b) final SEM model.

Table 5: SEM goodness of fit criteria.

Criteria	Value
Standardized Root Mean Square Error (SRMSR)	0.0546
Goodness of Fit Index (GFI)	0.903
Adjusted GFI (AGFI)	0.7504
Bentler Comparative Fit Index	0.914

Table 6: Covariance Matrix among the criteria.

	Environment	Social	Economy	Technology
Environment		0.93392 <0.001	0.59841 <0.001	0.81588 <0.001
Social			0.68086 <0.001	0.85475 <0.001
Economy				0.61768 <0.001
Technology				

Table 7 illustrates the results of the standardized estimates of all dimensions and their factors with their p-value. This shows that for each hypothesis tested, the parameters are all significant as they show a p-value less than 0.001 with positive correlation. Therefore, the triple bottom line of sustainability; environmental, social, and economic has a positive impact on dwellers' perception to select 3D printed units.

Table 7: SEM path list.

Path	Parameter	Estimate	Standard Error	t-value	p-value
Environment → E1	1	0.56702	0.04941	11.4755	<.0001
Environment → E2	2	0.54530	0.05121	10.6472	<.0001
Environment → E3	3	0.57725	0.04943	11.6788	<.0001
Environment → E4	4	0.67531	0.04233	15.9544	<.0001
Environment → E5	5	0.57058	0.04972	11.4749	<.0001
Environment → E6	6	0.62560	0.04578	13.6665	<.0001
Environment → E7	7	0.62450	0.04586	13.6172	<.0001
Social → S1	8	0.53768	0.05007	10.7385	<.0001
Social → S2	9	0.67945	0.04026	16.8748	<.0001
Social → S3	10	0.71206	0.03741	19.0344	<.0001
Social → S4	11	0.61435	0.04450	13.8047	<.0001
Social → S5	12	0.62212	0.04388	14.1767	<.0001
Social → S6	13	0.65135	0.04155	15.6780	<.0001
Economy → C1	14	0.73454	0.04189	17.5364	<.0001
Economy → C2	15	0.68953	0.04454	15.4826	<.0001
Economy → C3	16	0.74706	0.04121	18.1296	<.0001
Technology → T1	17	0.70709	0.03853	18.3509	<.0001
Technology → T2	18	0.73943	0.03595	20.5693	<.0001
Technology → T3	19	0.66699	0.04171	15.9922	<.0001
Technology → T4	20	0.67351	0.04120	16.3489	<.0001
Perception → Commitment	21	0.44094	0.04740	9.3028	<.0001
Env → Perception	22	0.59794	0.49584	1.2059	0.2279
Social → Perception	23	1.07471	0.61347	1.7519	0.0798
Economic → Perception	24	0.14844	0.13020	1.1400	0.2543
Technology → Perception	25	0.31498	0.18967	1.6607	0.0968

4.2 Discussion

The 3D printing dwellers' perspective have been studied considering the sustainability triple bottom line in addition to technology and was checked through the SEM modeling. Although, the relationship was not immediately identified, where also the literature review has shown the lack of such relationship, However, the SEM and data collected had helped modeling the relationships and the impact of the sustainability dimensions on the dwellers' perspectives which was backed up by the collected data. The CFA has showed the relationship between the sustainability dimensions and has indicated that all of them are significant indicators to the dweller's perspective whereas the SEM has shown the relationship between each dimension and its indicators to impact the dwellers' perception towards 3D printed residential households. Thus, the provided information would assist developers, municipalities, policy makers and dwellers alike when designing or studying the urban settings required for the 3D printed buildings and the perception of the occupants to be their highest priority. Meanwhile, the academic sector can benefit as well from this study to develop more efficient technologies and methodologies to overcome the challenges associated with this technology to satisfy the intended stakeholders. Therefore, many further studies to benefit from this as the technology is still new and that the human factor for the purpose of moving into 3D printed households is to be part of any investment strategy.

5. Conclusions

In conclusion, dwellers' perception was measured towards 3D-printed residential units and their commitment to sustainability. A Structural Equation Modelling (SEM) approach was used to measure the intended latent variables which are social, environment, economic, technological, dwellers' perception and commitment through selected factors from the literature review. It showed that all selected factors are significant in the model and all of them have been retained. Moreover, there is positive impact of dwellers' perception towards selecting 3D-printed units and their commitment towards sustainability through the selected factors. In summary the academic sector can benefit from this study to develop more efficient technologies and methodologies to overcome the challenges associated with this technology to satisfy the targeted stakeholders.

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