IDENTIFICATION OF VIABILITY FACTORS IN ADDITIVE MANUFACTURING TECHNOLOGY FOR RESIDENTIAL BUILDING CONSTRUCTION

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ABSTRACT

Residential building construction is one of the endless activities which demand more labor and plenty of time. Even after the tremendous innovations in construction sector, still few activities consume more time and labor. Laying of Concrete is one such activity, quantum of research has been carried out in strength and behavior of concrete but only limited studies were discussed about laying of concrete. Additive Manufacturing or 3D concrete printing is portrayed as a promising solution for the above said problem. Since the technique is in its initial stage, so this work attempts to identify the viability factors for implementing 3D concrete printing in residential building construction. From the available literature, a pertinent questionnaire has been prepared regarding suitability by considering the following parameters materials, cost, technical knowledge, labor and time. The questionnaire designed in such a way to reflect the perspective of stakeholders and personnel who are interested in or are working with 3D printing. The survey results were analyzed using statistical analysis tool and the results were discussed. In addition this study focused the viability of 3D concrete printing in the context of energy efficiency in construction.

Keywords: 3D printing, Additive Manufacturing, Residential building, Viability

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1. Introduction

Construction sector is one of the prominent sources of world GDP. It contributes almost 6% of the world GDP. It is very clear that engineering and construction sector is undoubtedly a pillar of the global economy [1]. In order to enhance productivity and promote construction rate construction firms are constantly looking for innovative ways in optimum cost [2]. Plenty of technologies were evolutes in the past decade; additive manufacturing is one such technology. One of the most recent technological advancements in the building sector is additive manufacturing (AM), sometimes known as 3D printing is one of the most recent technology in construction sector which enables speedy construction with higher precision.

The International Organization for Standardization (ISO) and the American Society for Testing and Materials (ASTM) define AM as "the process of combining materials to construct objects using 3D model data, often layer by layer" [3]. By creating successively layered, thin layers of material, 3D printing is the method of creating an object from a three-dimensional model [4]. 3D printing aids in resolving environmental problems. It is well known that the building sector is one that both uses a lot of resources and puts a lot of strain on the environment [5]. AM also enhances architectural freedom [6].

Significantly less time is needed for 3D printing construction, the most frequently mentioned advantage of 3D printing is faster construction [2], [5], [7], [8], [9], [10], [11], [12], [13], and [14]. Most of the authors revealed that using of 3DCP results in decrease of building cost [5] [14]. In the aspect of environmental benefit an appreciable reduction in construction waste was noticed while using 3D printing [7]. 3D concrete printing decreases the frequency of accidents and fatalities that occur on-site and a paramount safety was ensured.

Even though with numerous advantage, AM has its own challenges in implementation. The key ingredients used for 3DCP is completely varies with conventional material, new variety of materials in unusual size and proportion is used for 3DCP. From existing papers, printability and build ability are the main issues that can be used to summaries the challenges in materials. Scalability, directional dependencies are issues with 3D printers. In addition the size of construction projects creates addition complication in 3D concrete printing [4], [10], [11], [15], [16], [17], and [18]. Building services' exclusion, the integrity of the structure, and the suitability of the construction location are among the design and construction issues. It can be difficult to exclude building services like electrical and mechanical. [5], [19]. Structural integrity is yet another significant issue. [5], [8], [16], [17], and [19]. According to Berman [18], printing load-bearing components has been difficult because the quality of the printed pieces has been found to be fragile. Another difficulty is setting up a construction site. [2], [19], [20], [21]. The open environment of a construction site may not be suited for a 3D printer, which requires a more regulated environment

Published works as mentioned above by various authors provide details regarding application, benefits, challenges, and demerits of using 3D concrete printing in construction projects. Most of the researchers revealed that material, labor, technical information are the parameters which influences the implementation of 3DCP. The instruments which was used for 3DCP has its limitation, that it was used only in the fabrication unit. On site 3DCP has not reached a substantial level of application and only small scale projects alone constructed using this technology. A very minimal research and guidelines are available for implementing 3DCP in small scale residential building construction. In order to shed a light over this issue, in this work the key viability factors for successful implementation of residential building constructions were identified in the perspective of stakeholders. The test results are analyzed using CVR method and the importance of the above said parameters is proposed to be addressed.

2. Identification of viability factors

Although 3DCP moving towards the pinnacle but few parameters need to be addressed effectively for smooth implementation. Based on the extensive literature survey viable key parameters are identified. The influence of the said parameters was assessed by conducting questionnaire survey with the stakeholders. The questionnaire was completely designed in such a way to address the viability of implementing 3DCP in residential building construction. In this work questions were prepared under four category; Material, Labour, Cost and Technical Knowledge. Five to eight questions were prepared for each parameter in such a way to depict the exact influence of the parameters on successful implementation of the 3DCP. The questionnaire was communicated to stake holders as well as engineering students, professionals and also the persons those who are interested in 3DCP.

2.1 Material

Material is one of the prime factors which influence the 3DCP. The particle sizes, availability, compatibility of the materials are noted as parameters with high importance. Similar importance also given to testing of ingredients. On review, the following parameters found suitable for analyse the influence of material on 3DCP.

- Availability of Material
- Reduction in material usage
- Limitations in Material selection
- Testing facility for material
- Ecofriendliness of material
- Materials utilized compliant with the codes and standards.

2.2 Labour

3DCP is not completely automated system of construction, it also demands sufficient amount of labour for implementation. But the technological requirement in 3DCP confines only with skilled labour hence the labour selection and requirement are not matches with the conventional system of construction. On considering above issue the following sub parameters are designed in labour perspective.

- Effect of Manpower requirement
- Adequate Technical Knowledge
- Exposure to 3DCP
- Skill based Training
- Adoptability

2.3 Cost

Literature reveals that a reasonable reduction in construction cost was observed on using 3DCP, but the initial cost of the machineries found high. So on calculation of construction of cost it is mandatory to include the machine and installation cost these results in appreciable variation in the construction cost. The parameters which substantially influencing the cost are mentioned below.

- Reduce cost of construction component/structure
- Freedom of design at no extra cost
- Initial Installation cost
- Maintenance cost

2.4 Technical Knowledge

Since the technology has recent origin, so the technical details and inputs are not sufficiently adequate. The requirement in the technical perspective is comparatively high. The importance of technical knowledge and affecting factors are prioritized and discussed below.

- Lack of Standards
- Availability of design principle
- Flexibility in design
- Easy computer based design process
- Suitability of printing

3. Data Analysis

The questionnaire was prepared in Google form and shared to almost 300 persons include, project managers, practicing engineers, scientist, academician, labors, students and also to the persons those who are interested in 3DCP through email and other internet sources. Out of 300 surveys communicated, only 87 have responded. Among the 87 responses, fourteen responses were incomplete, so totally 73 responses are considered for analysis.

3.1 Analysis of Respondent

Out of the responded 73 persons, twenty three were from practicing engineer, sixteen belongs to R& D services, six from construction project management sector, twenty eight from academic institutions. The pictorial response shown in figure 1

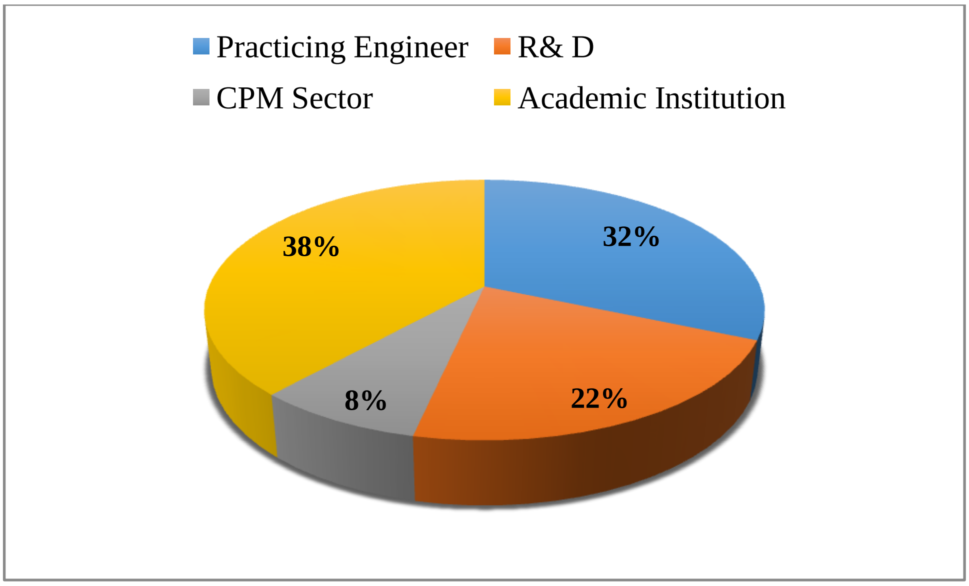

Figure 1 Distribution of respondent by area of practice

Years of experience of the respondents was collected through the survey. It ranges from 3 to 25 years. The variation is shown in figure 2

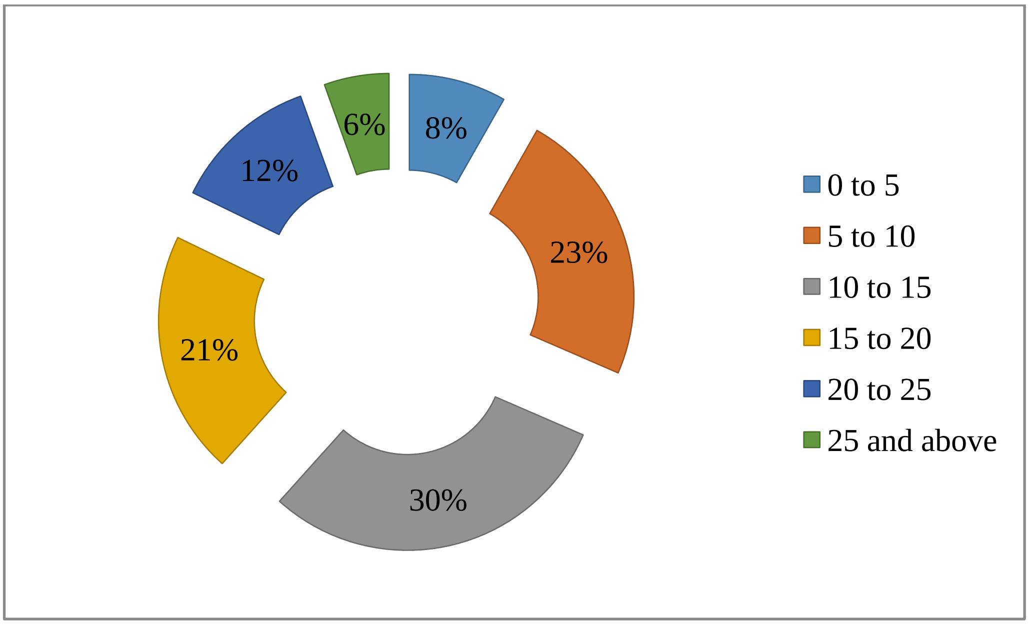

Figure 2 Distribution of respondent by experience

In addition, the education level of the respondents was categorized in six groups, High School, Diploma, under graduation, Post graduation, Doctorate and other technical education. In this no responses was fall under high school category, the variation in remaining all other category are shown in figure 3

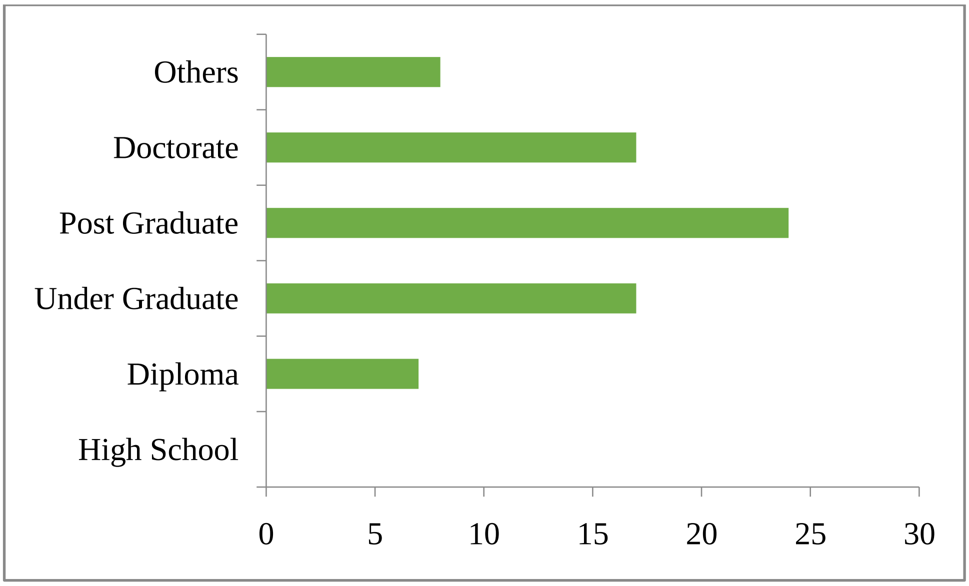

Figure 3 Distribution of respondent by education level

3.2 Analysis of Response

According to Lawshe's method [22], the content validity ratio (CVR) for each parameter was computed and based on the results significant of each parameter was assessed. The formula for calculating CVR is given by

$$\mathrm{CVR} = \frac{n - \frac{N}{2}}{\frac{N}{2}} \text{........ Eqn (1)}$$

Where,

CVR = Content Validity Ratio

n = number of respondents who rated the item ‘3’, ‘4’ or ‘5’

N = Total number of respondents

All the parameters are measured in five point scale with 1 indicate the poor or disagree and 5 for strong agreement. For CVR computation (Lawshe et al) the respondent who opt 3, 4 and 5 are alone was considered for analysis. The value of CVR value usually ranges between 0 and 1, the parameter which is having CVR value closer to 1 was considered as more essential and vice versa (Wilson et al.) The value of CVR and average importance for each parameters are computed and presented in the below Table 1 to Table 4

Table 1 Response analysis for Material

S.No	**Parameters**	**Ranking of Response**					**Content Validity Ratio**
		1	**2**	**3**	**4**	**5**	
1	Availability of Material	2	3	22	22	24	0.863
2	Reduction in material usage	10	10	18	19	16	0.452
3	Limitations in Material selection	8	10	19	21	15	0.507
4	Testing facility for material	2	7	18	24	22	0.753
5	Ecofriendliness of material	9	2	17	23	22	0.699
6	Materials utilized compliant with the codes and standards.	2	6	18	24	23	0.781

Table 2 Response analysis for Labor

S.No	Parameters	Ranking of Response					Content Validity Ratio
		1	2	3	4	5	
1	Effect of Manpower requirement	1	6	21	22	23	0.808
2	Adequate Technical Knowledge	2	1	21	23	26	0.918
3	Exposure to 3DCP	6	2	19	22	24	0.781
4	Skill based Training	2	7	24	18	22	0.753
5	Adoptability	2	5	17	24	25	0.808

Table 3 Response analysis for Cost

S.No	Parameters	Ranking of Response					Content Validity Ratio
		1	2	3	4	5	
1.	Reduce cost of construction component/structure	2	3	22	22	24	0.863
2.	Freedom of design at no extra cost	4	14	18	20	17	0.507
3.	Initial Installation cost	8	3	16	21	25	0.699
4.	Maintenance cost	2	7	22	24	18	0.753

Table 4 Response analysis for Technical knowledge

S.No	Parameters	Ranking of Response					Content Validity Ratio
		1	2	3	4	5	
1	Lack of Standards	2	3	22	22	24	0.863
2	Availability of design principle	2	3	14	22	31	0.836
3	Flexibility in design	8	10	19	21	15	0.507
4	Easy computer based design process	7	3	24	17	22	0.726
5	Suitability of printing	1	4	17	23	28	0.863

4. Results and Discussion

Based on analysis of questionnaire survey the various parameter and sub parameters are viewed and the viability factors are identified.

4.1 Material

The variation of sub parameters in material category is shown in figure 4. Out of the five sub parameters, priority is given to availability of materials and reduction in material usage found less essential. Code utilization also found more essential next to material availability.

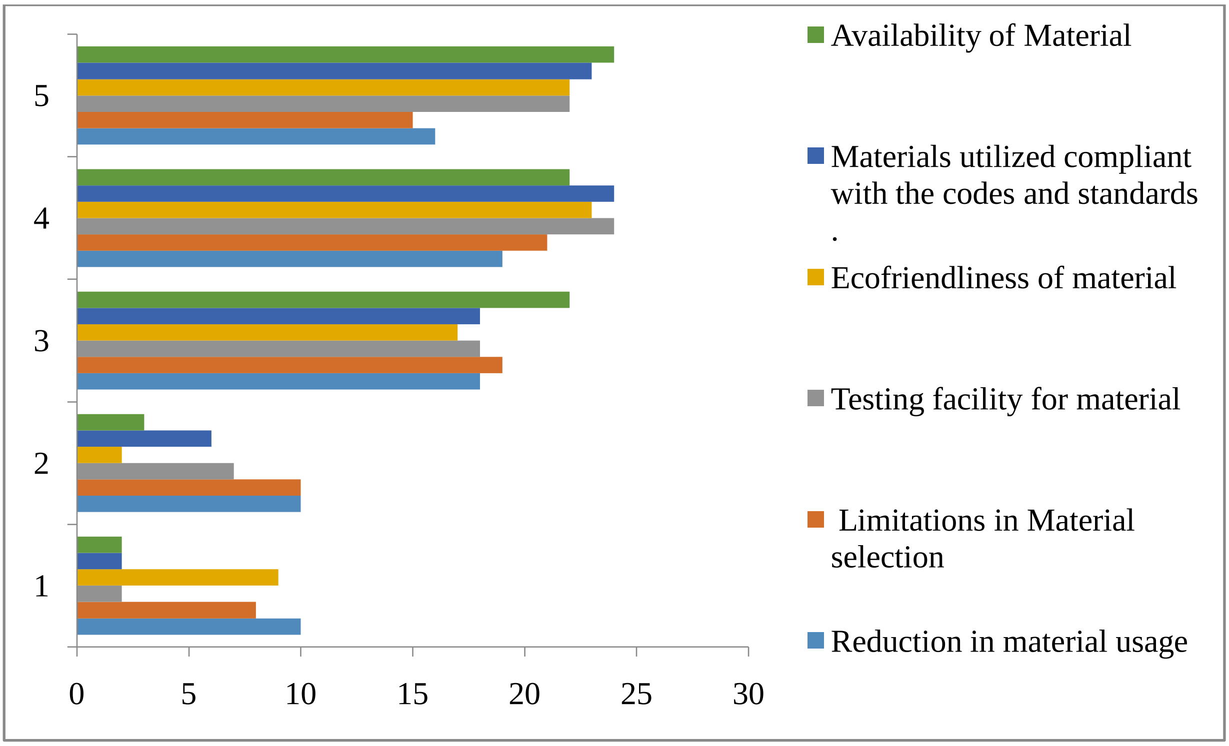

Figure 4 Ranking of Response for Materials

4.2 Labor

Figure 5 shows the variation in analysis response for the Labor parameter. Adequate technical knowledge found to be more essential and less importance is given to skill based training. Adoptability of labor and effective manpower are also identified as equally essential.

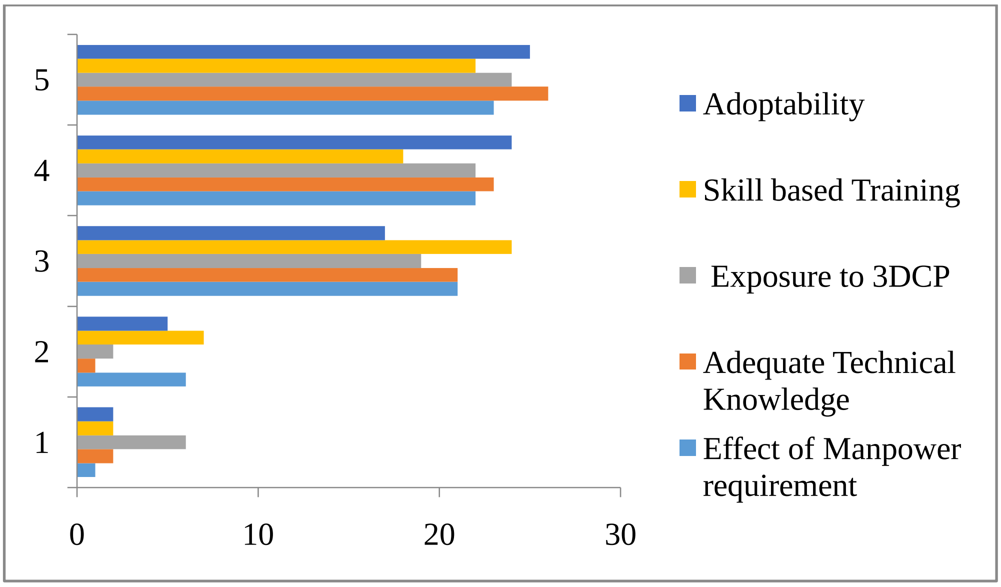

Figure 5 Ranking of Response for Labor

4.3 Cost

On detailed analysis of the questionnaire in the perspective of cost, a paramount important has been given to construction cost. Freedom of design at no extra cost seems less essential. The variation effect is shown in figure 6.

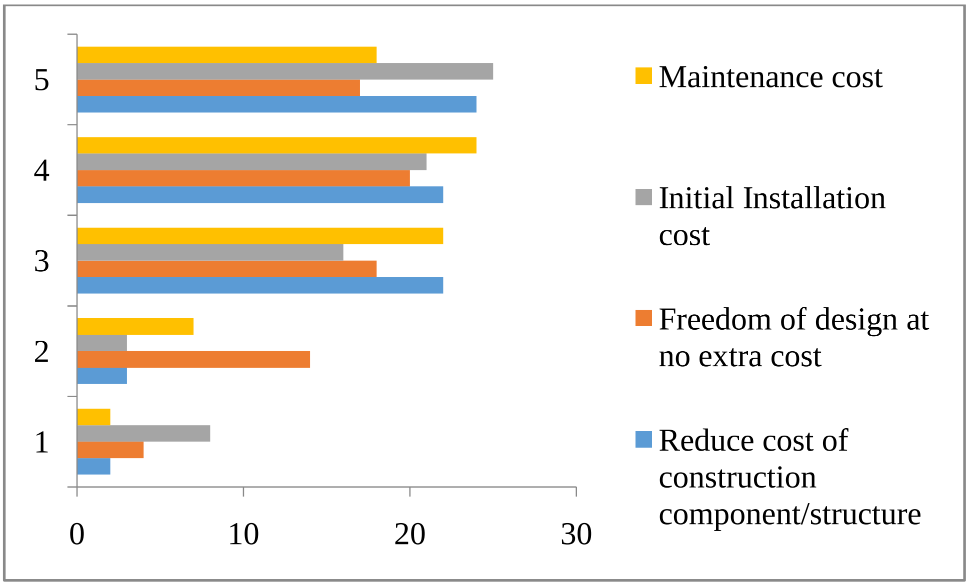

Figure 6 Ranking of Response for Cost

4.4 Technical Knowledge

Lack of technical knowledge and non availability of standard procedures are some of the challenges in 3DCP. The variations of questionnaire results are presented in figure 7. Lack of standards stands more essential and flexibility in design found less essential. Remaining all other parameters are comparatively equally essential.

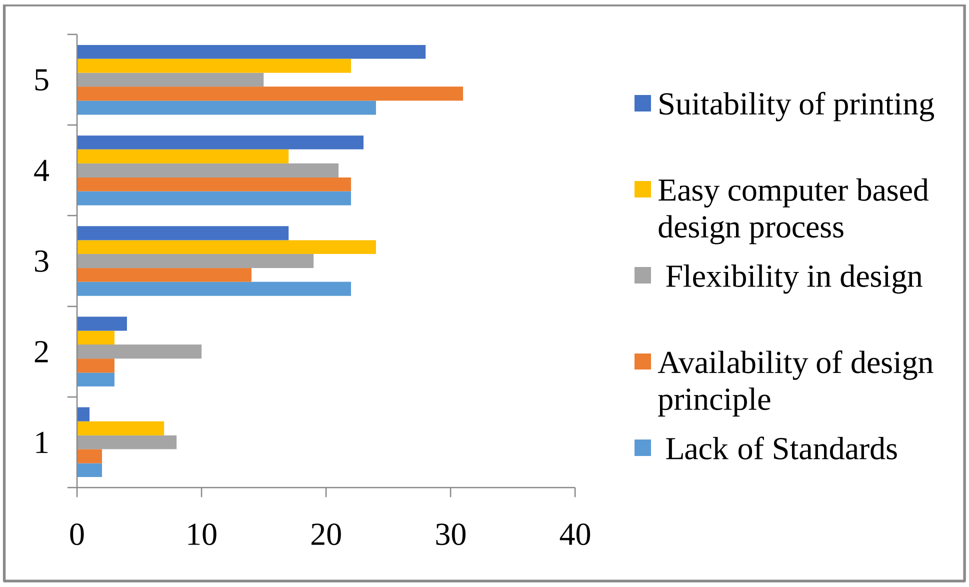

Figure 7 Ranking of Response for Technical Knowledge

5. Conclusion

A vigorous research has continuously been taken place in the area of 3D concrete printing but it is very unfortunate to note that the application of 3DCP is still limited. This paper makes an attempt to identify some key viable factor for smooth implementation of 3DCP for residential building construction work. From the extensive literature review and proper analysis of responses collected form questionnaire survey conducted from various stake holders the following conclusions were drawn.

As an initial research, in this work four factors such as material, labor, cost and technical knowledge and 20 sub parameters were identified as key influencing factors for implementing 3DCP. The responses are analyzed based on the content validity response (CVR), out of the twenty parameters the following found more vital.

1. Availability of material highly influence the 3DCP implementation

2. Lack of domain knowledge results in unwanted delay in execution. Hence a corrective measure on gaining adequate technical knowledge appreciably influences the 3DCP.

3. Cost is the key parameter which always decides the existence of technology. The technologies with more deviation from conventional in the aspect of cost are always end up in negative result. The analysis results reveals that construction cost is one of the essential parameter need to be taken care on implementing 3DCP.

4. The standard execution procedures are the documental source which has been used for carry out any work with fullest quality. Due to recent origin, 3DCP has lack of standards. Creation of standard procedure for 3DCP is considered as one of the viable factor for 3DCP implementation.

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Conflict of Interest

The authors have no conflict of interest in the production of this research article.

Availability of data and Materials

Not Applicable

Code Availability

Not Applicable

Authors' contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by P.Latha and V.A.Shanmugavelu. The first draft of the manuscript was written by P.Latha and other author commented on manuscript. Both authors read and approved the final manuscript.

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