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An Investigation into the Application of 3-D Printing to Construction Projects in Ningbo, China

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Abstract*: 3-D printing brings huge potentials to construction projects such as time, cost, quality and safety. Objectives of construction projects can be enhanced and achieved with superior performances. This research has investigated the perceptions of construction engineers towards the benefits and obstacles of 3 –D printing in construction projects. The questionnaire survey was conducted in Ningbo, China. The survey participants include building engineers, architects, civil engineers, project managers, MEP engineers and consulting engineers. A total of 100 replies were received. The respondents show very positive perceptions towards the benefits of 3-D printing. 'Reduced material wastage', 'reduced equipment usage' and 'improved safety in construction site' are the top three benefits. The obstacles are related to technical competence, materials and size/cost of 3-D printer. Outcomes of the survey are discussed in detail with future researches, especially the integration between 3-D printing and Building Information Modelling (BIM).

***Index Terms*: 3-D printing, Construction, Benefits, Obstacles.**

I. INTRODUCTION

3-D printing is one of the most revolutionary technologies in the construction industry to increase the speed of construction and reduce the cost of the project. Chinese construction companies have made significant contributions in the development of construction 3-D printing technology. Good examples are the world's tallest 3-D printed building in Suzhou, China (Archdaily, 2015) and the world's first functional 3-D-printed building in Dubai (The Telegraph, 2016). However compared to aerospace, defense and automobile industries, the construction industry is still in its infant stage of 3-D printing (Anjum et al. 2017 and Wu et al. 2016). Further the full advantages and obstacles of 3-D printing need to be reevaluated to progress to the next stage of development in construction. In this research, Ningbo was selected as the target city to be investigated. Ningbo, with a population of 7.6 million, represents the southeastern coastal cities of China, where the rapid economic growth has been achieved alongside with Shanghai.

The objectives of this research are:

to identify the benefits and obstacles of current 3-D printing technology in the China construction industry.

to investigate the perceptions of construction engineers in the application of 3-D printing to construction projects.

II. LITERATURE REVIEW

Definition of 3-D Printing

3-D printing is an automated, additive manufacturing process for producing 3-D solid objects from a digital CAD model. Therefore, the 3-D CAD model will be sliced into a series of 2-D layers. These will be deposited by the printer to construct the model. (Bogue, 2013). There are five main types of 3-D printing technology. These are: 'Stereolithography', 'Fused deposition modeling', 'powder based technique', 'Selective laser sintering and selective heating sintering' and 'Extrusion-based technique' (Nematollahia et al., 2017 and Wua et al., 2016). The first 3-D printer used stereolithorgraphy technology by Charles Hull in 1986, with a bean of UV laser to harden the liquid polymer and lower the platform to create multiple layers.

3-D Printing in Construction

One of the most important materials in construction projects is, without doubt, concrete. Large-scale 3-D concrete printing processes in the construction and architecture were proven feasible by concrete printing technology (Lim et al. 2012). The extrusion-based technique was used to extrude cementitious material from a nozzle mounted on a gantry to print a structure layer by layer. The size of the concrete products would produce enough capacity to print basic precast concrete components. Further, the material used in concrete printing was a high performance fiber-reinforced fine-aggregate concrete, which resulted in superior properties of material. Power based techniques and contour crafting technology, another form of extrusion-based technique, are also used to print out concrete material.

Case Studies of 3-D Printing by Chinese Construction Companies

WinSun Decoration Design Engineering built ten single story houses with 3-D printing technology under 24 hours. The houses were built with printed prefabricated panels.

(Archdaily, 2014). WinSun also constructed the world's tallest five-story apartment block and a 1,100 square meter mansion with internal and external decorations (Archdaily, 2015).

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Yingchuang Building Technology Co. built the world's first functional 3-D-printed office building in Dubai in 17 days (The Telegraph, 2016)

3-D Printing and Building Information Modelling (BIM)

During last five years, BIM has been successfully used to implement 3-D printing for construction projects (Wu et al. 2016). With BIM, more accurate digital models can be developed. These virtual models contain precise geometry and data needed for construction, prefabrication and procurement activities for the building to be realized (Eastman et al., 2011). Most of BIM software can export a file in proper format (i.e. Standard Tessellation Language format) which is directly converted into a set of instructions for the print. Interaction between 3-D printing and BIM provides systematic ways of analyzing connection strength, printing methods, and appearance (Wu et al. 2016).

3-D Printing and Life Cycle Costing (LCC)

Labour, material, and plant are three major items of construction cost. As the 3-D printing is an automated process, the requirement of labour can be greatly reduced (Buswell et al., 2006). However, the cost of 3-D printer and software packages required to edit and compile the source code should be included in the life cycle cost. The price of 3-D printers has been reduced significantly over the years, which allows private companies to procure own 3-D printers. (Bradshaw et al., 2010).

III. Research Methodology

Induction approach has been adopted together with a quantitative questionnaire survey to generalize the perceptions of construction engineers towards 3-D printing in Ningbo, China. The questionnaire was disseminated through WeChat and 100 replies were collected. Likert scale of five levels were used in the questionnaire: 1. strongly agree 2.agree 3. neither agree nor disagree 4. disagree 5. strongly disagree.

Survey Undertaken

Advantages and obstacles of 3-D printing in construction have been identified through literature review (Anjum et al. 2017, Nematollahia et al., 2017, Wu et al. 2016, Lim et al. 2012, Bradshaw et al., 2010, Buswell et al., 2006) and the perceptions of construction engineers towards the advantages and obstacles have been investigated.

Demographics of Survey

Table 1, 2 and 3 shows the demographics of the survey participants. The participants are composed of various professions in the construction industry. Building engineer, architect and civil engineer are the major ones.

Table 1. Professions of respondents

Profession	Percentage
Building Engineer	26%
Architect	22%
Civil Engineer	20%
Project Manager	16%
MEP Engineer	10%
Consulting Engineer	6%

Most of survey respondents have working experience between 2 and 10 years (74%) and 23% of them have experience less than 2 years. Only 5% of the participants shows more than 10 years of experience. As the survey was conducted with WeChat, most of the survey respondents are comparatively young generations. Therefore, the survey outcomes are reflecting future trends in the construction industry very well.

Table 2. Working experience of respondents

Working experience	Percentage
Less than 2 years	23%
Between 2 and 5 years	49%
Between 6 and 10 years	23%
Between 11 and 20 years	5%

Most of the survey participants are working at small and medium size companies, employees ranging between 20 and 500.

Table 3. Number of employees in the company

Number of employees	Percentage
Less than 20	5%
Between 20 and 100	67%
Between 100 and 500	23%
Between 500 and 1000	5%

Outcomes of Survey

Table 4 shows the perceptions of survey participants towards the advantages of 3-D printing. The best benefit is 'Reduced material wastage' (81%). All of the other benefits, except 'Improved utilisation of BIM', received high percentage score between 76% and 69%. The low score of 'Improved utilisation of BIM' is an unexpected outcome, considering the integration between 3-D printing and BIM.

Table 4. Survey outcomes - Advantages of 3-D Printing

Benefits	Percentage Score
Reduced material wastage	81%
Reduced equipment usage	76%
Improved safety in construction site	74%
Reduction of labour dependency	73%
Improved quality control	72%
Shortened construction time	71%
Customised buildings or houses	71%
Cost saving	70%
Improved constructability	70%
Automation/ DfMA	69%
Improved utilisation of BIM	33%

Table 5 shows the obstacles of 3-D printing in construction. The top two obstacle – 'Technology transfer' and 'Time/cost for training education' – are very much related to each other. The survey respondents perceive that technical competence is the most important obstacle to be overcome to implement 3-D printing. Material related obstacles – 'Strengths of materials' and 'Availability of suitable material' – are highly scored. In addition, 3-D printing machine related obstacles – 'Scale and size of 3-D printing machine' and 'High cost of 3-D printing machine' – are considered as important ones.

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Table 5. Survey outcomes - Obstacles of 3-D Printing

Obstacles	Percentage Score
Technology transfer	85%
Time/cost for training education	82%
Strengths of materials	75%
Economies of scale	71%
Scale and size of 3-D printing machine	67%
Availability of suitable material	66%
High cost of 3-D printing machine	65%
Printing structures in parts	53%
Lack of research and knowledge in 3-D printing	37%
Sustainability and durability of 3-d printed structure	34%
End user acceptability	27%
Printing complex structure	26%
Codes and guideline not developed	7%

Suitable structures with 3-D printing are shown in Table 6. As were publicly shown, house, bridge and building receive high scores compared to new civil engineering areas such as dam, railway and road/highway.

Table 6. Suitable Structures to Implement 3-D Printing

Structure	Percentage Score
House	64%
Bridge	54%
Building	52%
Dam	34%
Railway	31%
Road/Highway	27%

IV. DISCUSSION

Survey participants show very positive perceptions for the benefits of 3-D printing, which coincide with current researches. However, 'Improved utilisation of BIM' is not considered as a major benefit. This is an unexpected result considering the status of BIM implementation in construction projects and the potential integration between 3-D printing and BIM. Further investigation will be required to understand the causes of this discrepancy. Technical competence, materials and size/cost of 3-D printer are major obstacles. In case of materials, reinforcement can be an issue. This also require further research. The price of 3-D printer will eventually drop down. However, it might be still expensive to small and medium size companies. Life cycle cost will be required to efficiently and effectively procure a 3-D printer.

V. CONCLUSION

Benefits and obstacles of 3-D printing for construction projects have been identified. The perceptions of construction engineers in Ningbo, China towards the benefits and obstacles have been investigated through a quantitative questionnaire survey. Survey participants show very positive perceptions towards the implementation of 3-d printing in construction projects. Top three benefits are 'Reduced material wastage', 'Reduced equipment usage' and 'Improved safety in construction site'. Major obstacles of 3-D printing are related to technical competence, materials and size/cost of 3-D printer. One unexpected outcome of this research is that 'Improved utilisation of BIM' is not considered as a benefit. Further researches are required to clarify the causality of this discrepancy. Particularly whether this negative perception between 3-D printing and BIM is based on the local context or national level in China.

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