The influence of the critical diffusion factors of 3D printing technology on the success of UAE construction Projects

عوامل الانتشار الرئيسية لتقنية الطباعة ثلاثية الأبعاد التي تؤثر على نجاح مشاريع البناء في دولة الإمارات العربية المتحدة

by

MANSOUR EBRAHIM DAOUD FARIED

A dissertation submitted in fulfilment

of the requirements for the degree of

MSc CONSTRUCTION MANAGEMENT

at

The British University in Dubai

Dr. Khalid AlMarri

June 2018

DECLARATION

I warrant that the content of this research is the direct result of my own work and that any use made in it of published or unpublished copyright material falls within the limits permitted by international copyright conventions.

I understand that a copy of my research will be deposited in the University Library for permanent retention.

I hereby agree that the material mentioned above for which I am author and copyright holder may be copied and distributed by The British University in Dubai for the purposes of research, private study or education and that The British University in Dubai may recover from purchasers the costs incurred in such copying and distribution, where appropriate.

I understand that The British University in Dubai may make a digital copy available in the institutional repository.

I understand that I may apply to the University to retain the right to withhold or to restrict access to my thesis for a period which shall not normally exceed four calendar years from the congregation at which the degree is conferred, the length of the period to be specified in the application, together with the precise reasons for making that application.

____

Signature of the student

ABSTRACT

3D printing applications in the construction industry have gained the interest of field specialists, especially in UAE. This is particularly because of the fact that the UAE Government has recently announced its target that at least twenty-five percent (25%) of the new buildings in Dubai should be utilizing the 3D printing technology by the year 2030. This research is aiming to identify the 3D printing technology's critical diffusion factors influencing the success of the UAE's construction projects.

Through a critical review of the relevant literature, the study developed a framework based on the innovation diffusion theory developed by E.Rogers (Rogers, 2005); to identify critical factors leading to technology acceptance and, therefore, measuring the impact of those identified factors on the successful application of the technology in the UAE's construction projects. The literature findings have been examined via a quantitative approach through a designed questionnaire and a subsequent data analysis via SPSS statistics software.

The literature review identified thirty four factors classified under the five major attributes of technology diffusion following the innovation diffusion theory namely the relative advantage, the compatibility, the trail-ability, the complexity and the observability.

All those thirty-four factors were found to be with an evident association with the level of successful implementation and success of the 3D printed project.

The study suggests that the integration of all of these factors together will have a stronger level of influence and will lead to higher levels of application success. The study also suggests the classification of the relative advantage, compatibility and complexity as primary factors, and to classify the trial-ability & observability as secondary factors due to difference found in the level of influence that they have on the success of the project.

The study faced a limitation on the availability of specific literature related to the 3D printing in construction in general, and in the UAE market in particular. Similar technologies and similar markets have, however, been taken as reference in areas for which precise information was not available. Finally, the study suggested a list of recommendations to be adopted by market stakeholders based on the research findings to facilitate the achievement of the government target.

Key Words: 3D printing, innovation, UAE, Construction

ملخص :

اكتسب تطبيق الطباعة ثلاثية الأبعاد في مجال الإنشاءات اهتمام المختصين و الخبراء فى هذا المجال، خاصة في دولة الإمارات العربية المتحدة بسبب إعلان الحكومة الإماراتية لهدفها بالوصول الى نسبة خمسة وعشرين بالمائة (25٪) من مشاريع البناء الجديدة في امارة دبي اعتمادًا على منهجية الطباعة ثلاثية الأبعاد بحلول عام 2030 .

و بناء عليه, فان هذا البحث يهدف إلى التعرف على تقنية الطباعة ثلاثية الأبعاد، وتحديد عوامل انتشارها الرئيسية التي تؤثر على نجاح مشاريع البناء في الإمارات.

من خلال مراجعة نقدية للأبحاث السابقة ذات الصلة بموضوع البحث، طورت هذه الدراسة إطارًا منهجيا لتحديد العوامل الحاسمة المؤدية إلى قبول التقنية استناداً إلى نظرية نشر الابتكار (innovation diffusion theory) ، ومن ثم قياس تأثير تلك العوامل على التطبيق الناجح لهذه التقنية في مشاريع البناء الإماراتية.

هذا وقد تم فحص النتائج باستخدام منهج التحليل الكمي من خلال استبيان مصمم خصيصيا لهذا الغرض وتحليل البيانات لاحقا من خلال برنامج الإحصاء.SPSS

تم تحديد ثلاثة و ثلاثين عاملا من عوامل الأنتشار الرئيسية مصنفة تحت االفئات الخمس الرئيسية لانتشار التقنية حسب نظرية انتشار الابتكار و هم: الميزة النسبية ، التوافق، قابلية الأختبار، التعقيد والملاحظة.

جميع هذه البنود الثلاثة والثلاثين وجدت فى ارتباط وثيق مع مستوى نجاح مشاريع الطباعة ثلاثية الأبعاد.

اشارت الدراسة ايضا إلى أن تكامل جميع العوامل معًا سينتج عنه مستوى اقوى من التأثير و بالتالى سيؤدي إلى فرص اعلى لنجاح تطبيق التقنية، كما أوضحت نتائج الدراسة ان عوامل الميزة النسبية والتوافق والتعقيد هي عوامل أساسية و ذات تاثير اقوى، مما نتج عنه تعديل الأطارالنظرى المقترح لتحديد تلك العوامل الثلاثة كعوامل أساسية في حين أن تحديد العاملين الأخرين (القدرة على ألاختبار و الملاحظة) كعوامل ثانوية.

من اهم العوائق التى واجهت هذه الدراسة هوعدم توفر المرجعيات و الأبحاث السابقة المتعلقة بالطباعة ثلاثية الأبعاد في الإنشاءات بشكل عام، وفي السوق المحلى لدولة الإمارات بشكل خاص، ومع ذلك، فقد تم أخذ تقنيات مماثلة وأسواق مماثلة كمرجع لعدم توفر المعلومات الدقيقة.

وأخيراً، اقترحت الدراسة قائمة بالتوصيات التى يمكن تبنيها من قبل المهتمين و اصحاب القرار المؤثرين في مجال التشييد و البناء فى الإمارت لتسهيل تحقيق الهدف الحكومى المتمثل بتطبيق التقنية فى السوق المحلى.

Dedication

This dissertation is dedicated to the soul of my beloved father, although he would be the most proud person with my current achievement, he was unable to witness my graduation.

I dedicate this dissertation also to my small family, my wife and my son, who sacrifice a lot in order to facilitate the proper environment for me to complete my study and research beside my work. Thanks for both of you.

Finally, Special thanks and appreciation to my academic supervisor, Dr. Khalid Al Marri for all the Guidance and motivation to remain on track from the beginning to completion.

Table of Contents

List of Figures

List of Tables

List of abbreviations

3D: three dimensional

UAE: united Arab Emirates

IV: Independent variable

DV: Dependent variable

BIM: Building Information Modeling

R&D: Research and development

HSE: Health, safety & Environment.

OOTF: office of the future

TAM: technology acceptance model

1. INTRODUCTION

Although the concept of three-dimensional (3D) printing as a form of additive manufacturing (Bos et al., 2016) is always promoted as a key form of innovation in several fields and industries, researches around that concept have been discussed since 1980s (Khoo et al., 2015). In the last four decades, the technology has witnessed immense development. Not only have a number of the challenges and limitations of the application of three-dimensional printing been overcome, but there have also been improvements in the machines, printing inks, and printing methodologies that are all essential parts of the field. (Canessa et al., 2013). As in the case of many other industries, the interest of construction specialists in utilizing 3D printing technology for printing buildings either fully or partially is increasing day by day, aiming to convert construction sites into large-scale printing fields. (Canessa et al., 2013).

The interest in 3D printing application in construction fields particularly in the United Arab Emirates (UAE) is evident and growing progressively (Design Middle East, 2018) not only because of the UAE's interest in becoming the world's leader in innovation in general (Schilirò, 2015), but also due to the announcement made by the Vice President and Prime Minister of the United Arab Emirates and Ruler of Dubai, His Highness Sheikh Mohammed Bin Rashid Al Maktoum, who declared it a government target that 25% of the new buildings in Dubai should be constructed using 3D printing technology by 2030. (Emirates 24|7, 2017)

Since the construction industry is well known for its reluctance towards innovation (Xue et al., 2014), applying new ideas or concepts for construction will be faced with noticeable hesitation from the market. This will be a great barrier in the application of new concepts. Furthermore, even though 3D printing technology is already almost 40 years old (Khoo et al., 2015), the incorporation of the technology in the world of construction is still in its nascent stages, and the construction industry is still far away from realistic and practical applications on a large scale with the required economic efficiency (Bos et al., 2016). It is these barriers that are standing in the way of widespread use of the technology and preventing the Emirates' target from being achieved. (Gao et al., 2015).

This research is concerned with the investigation and identification of critical diffusion factors that push towards more successful and widespread implementation of 3D printing technology in construction projects focusing on the context of the construction industry of the UAE in particular.

The research will start by looking at the history of the 3D printing technology, explaining the concept of the process, and then moving further towards the forms of application of the technology in the construction field, all while shedding light on the advantages and the current barriers of application.

Afterward, the literature review will be extended to identify the critical diffusion factors impacting the successful application of the 3D printing technology in the construction field, focusing on whatever is applicable in the local market of the UAE.

Findings of the research will be verified afterwards using a quantitative approach through a designed survey questionnaire. Since the research involves a psychological aspect related to diffusion of innovation (acceptance/ perception), expert opinions would be a valid and suitable method to examine and verify the research findings. After collection, the data will be tested and analyzed through the SPSS statistics software aiming for a deep understanding of various parameters and the magnitude of impact, as well as the correlation in between.

The research findings will be represented in a conceptual model, and a set of recommendations will be concluded as the base of present and future initiatives to be taken by various stakeholders to push the technology further towards the achievement of the pre-set government target.

1.1. Historical Development

The concept of forming a three dimensional object by stacking multiple horizontal layers over each other using a machine following a predefined computer program was discussed for the first time in the 1980s in some research and prototyping projects (Wong and Hernandez, 2012). The real birth of the 3D printing technology as we know it today is related to the development of the stereolithography technology by "3D systems" in 1986 (Melchels, Feijen and Grijpma, 2010). The basis of the concept is that the 3D object is first modeled using a computer into an "STL" file. This model is essentially just several sets of coordinate points – each of which forms one layer/slice of the outline of the object. The second phase involves using a photosensitive polymer which contains a resin (solidification agent) that will help convert the polymer from its liquid state to solid state once it gets exposed to an ultraviolet laser. With the help of this process, the 3D computer model can be converted into a real solid object through a machine called a 3D printer (Wong and Hernandez, 2012).

The next step was the Introduction of the Fused Deposition Model (FDM) in 1989 (Popescu, Stan, and Miclea, 2014). The technique in principle is utilizing a thermoplastic solid material which turns into liquid state by extrusion through a powered nozzle to a platform. The material will be immediately cured to form a solid object again and horizontal and vertical movements of the nozzle and/or platform according to certain coordinates (fed by the computer model) will help in the formation of the final shape of the 3D object. (Bosqué, 2015)

A common integral problem was found in both STL and FDM: the lower layer was required to support the upper layer. Due to this reason, the possibility of printing overhanging surface or cantilevers without the requirement of external support temporary scaffolding was mitigated (Dumas, Hergel, and Lefebvre, 2014). This problem was the motivation of a new series of 3D printers with used a technology called Selective Laser Sintering (SLS). This technology uses a process that is different than any of the processes that were used earlier for 3D printing. For Selective Laser Sintering, the machine uses a rectangular layer of loose and very fine granular material, which could be of different base as metal, ceramics or thermoplastic. A laser beam guided by a computer program is then used to go over a specific path on the loose particles layer, turning only the portions under contact with laser into solid, leaving the rest of layer loose as it is. After this, a full second layer of loose materials applied and so on. At the end of the process, the loose materials are removed, leaving only the solidified objects. This method has resolved the problem of overhanging parts of previous methods as the existence of a loose layer over the full printing surface will act as a temporary support for the next layer. While certain important problems were solved through this process, the final printing resolution was not as good as previous methods. (Calì et al., 2012), (Kruth et al., 2005).

1.2. 3D printing technology in Construction Industry

The possibility of utilizing 3D printing technology in the construction industry has been researched by several scientists, architects and field specialists since the late nineties (Pegna, 1997).Research on 3D printing especially became popular as professionals in the industry started to realize the benefits that could be attained from additive manufacturing in terms of sustainability, speed of construction, and higher HSE measures (Buswell et al., 2007). These aspects will be discussed in detail in section number 2.5.1.

Involvement of 3D printing technology in the construction industry is found to be evident in many forms and various scopes. This involvement can be divided according to the time of engagement into three main categories: pre-construction stage, construction stage, and post construction stage.

The simplest and most common form is to utilize the technology during the pre-construction stage to construct scaled marketing and study 3D models (Berman, 2013), which help to achieve higher quality models and more accurate details within notably shorter times and less cost (Perkins and Skitmore, 2015). This form is also important for building mock-ups, samples, and prototypes (Lim, 2012).

During the construction phase itself, 3D printing technology could be utilized in several different ways. It could be utilized to print the permanent structure itself, either fully or partially (Lim, 2012), or to print a temporary structure as formwork or temporary support elements (Heijmans, 2018). The technology also can be utilized for architectural purposes by printing architectural elements like blocks, partitions, cladding panels etc. (Gosselin et al., 2016). 3D printing technology could also be used in MEP works (Ritter, 2017) and external landscape elements to print external hard-scape elements (Green, 2014).

Finally, for the post-construction stage, 3D printing technology could be utilized to produce customized fit-out elements like fixed or loose furniture and certain (non-typical) replacement and spare parts according to certain needs. (Rayna and Striukova, 2016)

Figure 1 below will summarize the applications of 3D printing technology in the construction industry.

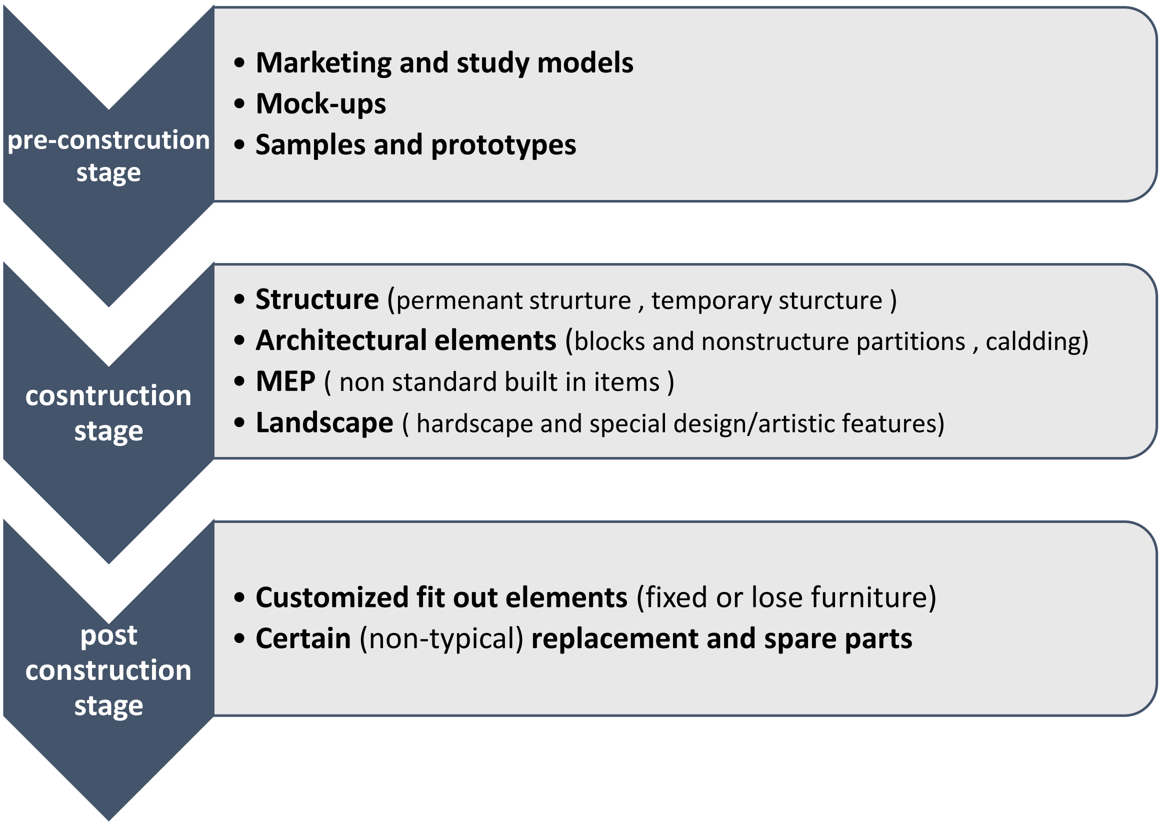

Figure 1: application of 3D printing technology in the construction industry

1.3. Cement-based ink 3D printing applications in the construction industry

Using cement-based ink to print construction elements in form of additive manufacturing is the most common approach for utilizing the 3D printing technology in the construction industry (Le et al., 2012). The concept was first proposed and introduced by Pegna (1997) and was described as a form of automation in construction. The process involved laying sequenced overlaid layers of a cement-based mixture (mortar) to form a large scale element using a robotic arm controlled by a computer.

The idea was further developed in various ways with developments in the printing materials, printing machines, and the printing method according to different requirement parameters such as integrity of the printed element, the speed of printing, the smoothness of the output (resolution), and the complexity of printed object design. Lim et al. (2012) have managed to classify the majority of these trails and came up with three main methodologies namely Contour Crafting, D-Shape and Concrete Printing.

1.3.1. Contour Crafting Method

Khoshnevis (2004) has described the contour crafting method as an application of additive manufacturing. The technology uses a computer system to guide a cement extruding nozzle and set of trowels to create form-free layers of materials according to preset coordinates. The main advantages of this method compared to other methods are better printing speeds and enhanced quality of the printed surface.

Contour crafting in the construction field can be seen in the form of a concrete disposing nozzle that will be attached to a gantry crane system which will be moved on guiding rails installed on site. The system can be used to print individual units with different designs (Lim et al., 2012). Figure 2 below will illustrate the application of the contour crafting method in construction sites.

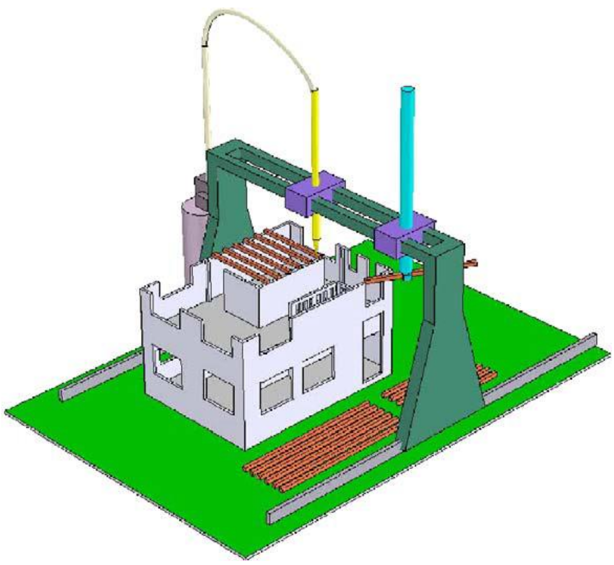

Figure 2: Application of contour crafting method in the construction industry

(Khoshnevis, 2004)

1.3.2. D-shape Method

The D-shape method works using a process that’s different than the process involved in the contour crafting method. In the D-Shape method, the machine lays a full layer of loose powdered materials. Next, a computer controlled nozzle is used to apply a binding agent on the area that needs to be hardened. After this, the next full layer of loose powder will be applied for the next layer and so on. After the completion of the printing process, loose materials which were not exposed to the binding agents will be blown away leaving only solidified objects (Le et al., 2012).

Due to the difference in printing techniques, the D-shaped method could overcome a major problem associated with previous Contour Crafting method which is printing the over-hanged and cantilever parts. At the same time, however, the printing speed of the D-shaped is much less, and strength of printed materials is also relatively lower compared to other methods. Naturally, this method is used for an entirely different purpose and with different elements in the construction industry. (Canessa et al., 2013).

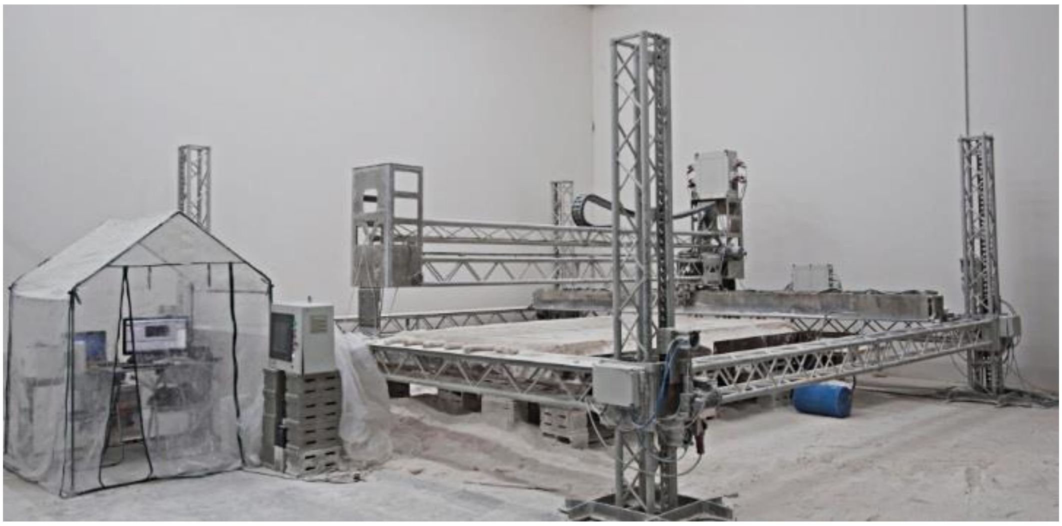

Figure 3: D-Shape printing Machine (D-shape.com, 2017)

1.3.3. Concrete printing method

The Concrete Printing method is in many ways similar to the Contour Crafting method as it extrudes a pre-mixed workable mortar through a computer controlled nozzle. The difference between the two techniques, however, lies in the fact that the concrete printing method case is used offsite (Lim et al, 2011). The technique also focuses on printing resolutions and material strength on account of member size and printing speed (Le et al., 2012).

Figure.4: Concrete Printing Machine (Lim et al, 2011)

1.4. 3D printing construction in UAE.

3D printing applications in the construction field have gained the interest of filed specialists (Canessa et al., 2013), especially in the United Arab Emirates (UAE), due to the recent announcement made by the UAE government in which it was declared that the government wishes to achieve the target of using 3D printing for the construction of 25% of the new buildings in Dubai by the year 2030. This announcement had been made by the Vice President and Prime Minister of the UAE and Ruler of Dubai, His Highness Sheikh Mohammed bin Rashid Al Maktoum, during the inauguration ceremony of the "office of the future" project (OOTF) on 23rd of May, 2016 (Foundation, 2017).

The OOTF is the pioneer project for the application of 3D printing technology in UAE. The project was inaugurated almost a month after the 3D printing strategy was launched in the UAE (Uaecabinet.ae, 2017) using a 6.5-meter high printer which had a 40-meter long computer controlled nozzle. The building was intended to be a prototype for further applications of the technology across the construction market in the city of Dubai (Ben-Ner and Siemsen, 2017).

However, there are several barriers which are hindering the implementation of 3D printing technology and cause real obstructions towards achieving the above mentioned target (Wu, Wang and Wang, 2016). Such barriers are affecting the decision makers' perception and acceptance of such technology, ultimately resulting in reluctance towards its adoption (Bos et al., 2016).

1.5. Research Gap

The extensive literature review resulted in finding several papers and researches concerned by the experimental application of 3D printing technology in the construction field as a laboratory study and prototypes. There is, however, an evident research gap on the wide and practical application of 3D printing technology on a broad scale, and precisely in the context of the local UAE construction market.

The research is focused on the field application of the technology in the construction industry. The research is further narrowed down to look at the application of the technology within the geographical boundary of the UAE as a response for the government's call to stretch the application of the technology within several fields – and in the field of construction in particular.

1.6. Problem statement

The problem associated with the above outlined research gap is the current market reluctance toward the wide application of the technology, and further hesitation of specialists to achieve the government target of the application of the technology.

1.7. Research Question

This research aims to answer the following question:

> *What are the critical diffusion factors that influence the success of 3D printing technology applications in construction projects in the UAE?*

Objectives of this study can be summarized as the following:

1- To conduct a comprehensive literature for the purpose of:
   a. Understanding the development history of the technology and how it is perceived as an innovation in construction.
   b. Investigating the relationship between technology acceptance and application of the technology.
   c. Understanding the innovation diffusion theory.
   d. Identifying the critical technology diffusion factors following the innovation diffusion theory
   e. Identifying the how the success of the project can be measured.

2- To assess the value added by the 3D printing technology application in the project compared to traditional method.

3- To evaluate the influence of technology compatibility with the local industry standard on the success of 3D application in the UAE's construction projects.
4- To evaluate the influence of the ability to try & test the technology on the success of 3D applications in the UAE's construction projects.
5- To evaluate the influence of the level of complexity of 3D printing technology on the success of 3D application in the UAE's construction projects.
6- To evaluate the influence of the level of 3D printing application observability on the success of the application of 3D printing technology in the UAE's construction projects.
7- To establish a relationship between 3D printing technology innovation diffusion factors and the success of construction projects in the UAE construction market.

1.8. Scope of the study

To answer the above mentioned research question, the scope of this study has been focused on two main targets:

1- To identify the critical factors which lead to technology acceptance, guided by the identified attributes of innovation diffusion as per the innovation diffusion theory.
2- To verify and confirm the relationship between the identified factors and the success of the technology application, and then use the identified critical diffusion factors as predictors to the success of the application of the technology.

1.9. Expected Implication

The expected implication of this study is the promotion of the application of the 3D printing technology in the UAE by focusing on critical diffusion factors and concluding a list of recommended actions to be undertaken by the influencing stakeholders in the UAE construction market. Those recommended actions will be based on the findings of the study and evident predictors and promoters for the acceptance and application of the technology.

Those recommended list of actions proposed by the study will help local markets to catch up with government target set for the application of 3D printing technology in the UAE's construction projects, and achieve the associated benefits with this target based on the potential benefits to be obtained from the application of the technology as explained in details the section 2.5.1.

1.10. Research structure and framework

The following chapters of this research can be summarized as the following

Literature Review: In this chapter, an extensive literature review will conducted to investigate former researches in line with study objectives as stated in section 1.7 above.

Conceptual frame work: Based on the literature review findings, null hypotheses will be concluded, and will be presented in a graphical conceptual model to reflect the relationship among the study variables.

Research methodology: This chapter will explore different research methods in both analytical and philosophical approaches, and will explain how the quantitative methodology with the deductive approach was found to be more appropriate for this study. This chapter will also explain why the survey questionnaire method has been chosen to collect data, and how the survey itself has been designed and tested via pilot tests.

Data Analysis: In this chapter, the collected data from the questionnaire will be tested and processed through the specific data statistical analysis software. The test results for each test have been reported, and the relevant acceptance threshold for each test has been indicated and highlighted.

Discussion: The result from the data analysis chapter will be deeply studied in this chapter and the study will demonstrate how to use the collected data and the test results to reject the null hypothesis and to accept the alternative hypotheses. In this chapter, the alignment between the test findings and the literature review findings will also be demonstrated, and further literature review is conducted to understand any flagged results.

Conclusion: Based on all of the findings of the study, this section will summarize the study results, and will conclude the list of recommendations as a practical implication of the study. In this section, the study limitation is also stated and future research opportunities are suggested. Figure 5 below will summarize the research structure and framework.

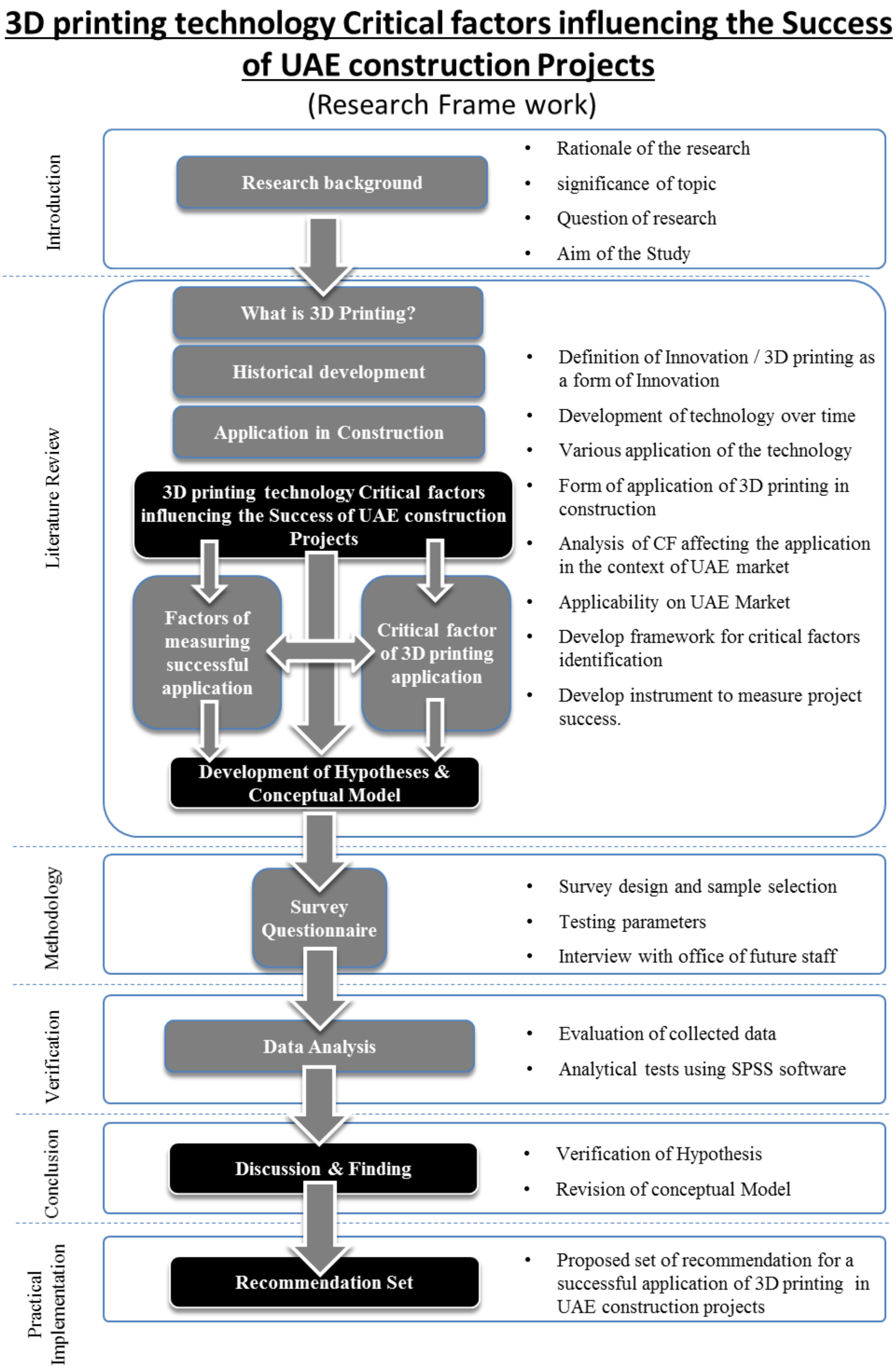

Figure 5: Research Framework

2. LITERATURE REVIEW

2.1. Introduction

As described in the previous chapter, and in order to find an adequate response to the research question in section 1.7, this research has examined the published literature relevant to the topic of the application of 3D printing technology in the construction market - particularly in the context of the UAE's local market. However, due to limited availability of literature on that specific topic, the literature review has been extended to cover similar forms of technology in construction, along with other applications of 3D printing in similar fields like construction, and the application of 3D printing in similar markets to the UAE construction market.

Extending the scope of literature review helped to predict the behavior of the development of 3D printing technology on the local market based on behavior of similar technologies, and taking into consideration similar applications and similar contexts.

This research philosophy and approach is to define the relationship and the impact of the acceptance of 3D printing technology on the rate of the success of its application which was proposed by published literature. This study suggests using the Innovation Diffusion theory as a guideline for the research. The reason for this suggestion and more details surrounding the topic will be explained in section 2.3. In the initial phase, however, definition of the 3D printing as a form of innovation is being proved. Additionally, the innovation diffusion theory which has been developed by E.Rogers (Rogers, 2005), will be utilized to explain the acceptance and diffusion of the 3D printing technology in construction. Finally, the five attributes of the innovation diffusion theory will be taken as guidelines to identify the critical diffusion factors, and summarize all the identified factors to be used as the independent variable on this study.

Successful application of 3D printing technology, on the other hand, can be measured by the rate of the success of projects where the technology has been applied, and in order to assess such success, further literature review has been conducted to identify project success measurement factors, and to come up with success factors which have been taken as the dependent variable in this study.

Data from the literature review has been taken as input for the theoretical framework and hypothesis in the next chapter.

2.2. 3D printing construction as a form of innovation

The construction industry has its own characteristics, which makes it unique compared to other fields. One of the most well-known characteristics, however, is the fact of being conservative, and reluctant to adopt new methods and innovation (Olatunji, Sher and Gu, 2010).

Innovation in construction has gone through different forms and has been defined either technical innovation which is related to methods, equipment, and materials, or organizational innovation which is focused on the project management and procurement approach (Murphy, 2014).

Since the application of 3D printing technology in construction is concerned with a new form of product delivery, in terms of materials, equipment & methods under the concept of automation (Khoshnevis, 2004) which is a major departure from the traditional and conventional method of construction (Buswell et al., 2007), we can consider it a form of technical innovation. The same conclusion has been also stated by Lim et al, (2011) when they described the deployment of 3D printing in construction as a "new concept of construction".

According to the above definition of technical innovation defined by Murphy (2014) using the Oslo Manual (OECD, 2005), 3D printing technology in construction can be categorized as technical innovation. Furthermore, Blayse and Manley (2004) conducted a research to identify major barriers for adopting innovative ideas in construction markets. That research highlighted how traditional procurement methods could stand as a great barrier against the implementation of the new and innovative ideas. They also suggested the adoption of innovative procurement methods in order to enable the application of innovation. The results of that have been found to be in line with what (Kumaraswamy and Dulaimi, 2001) have concluded as well.

So, as a conclusion for the above section, 3D printing technology application in construction is a form of technical innovation which requires association with organizational innovation in order to succeed.

2.3. Approach to assessing the success of 3D printing technology based on technology acceptance factors

There is a theoretical belief that there is a relationship between the acceptance of technology and its successful application, which was found to be evident in literature (Tornatzky and Klein, 1982), (Sonnenwald, Maglaughlin, and Whitton, 2001).

This approach was empirically examined by Polančič, Heričko, and Rozman, (2010) in a study that was aiming to examine the framework to assess the technology success based on its acceptance with the help of the technology acceptance model (TAM). The study suggested to accept technology acceptance attributes as factors to assess the success of a technology.

In section 2.2, 3D printing in construction has been found to be a form of innovation for the construction industry, and as a form of innovation, the innovation diffusion theory introduced by Everett Rogers in 1965 would be more representing the attributes of innovation acceptance, perception & diffusion (Rogers, 2005).

In chapter 2.4, innovation diffusion will be further explained. Additionally, innovation diffusion theory attributes will be used to define the critical factors impacting the successful application of 3D printing technology in the UAE's construction market.

2.4. Innovation Diffusion Theory

The theory of innovation diffusion was introduced by Everett Rogers in his book which launched in the year 1962 under name of "Diffusion of innovations" (Rogers, 2005). Ever since it has become known to the public, the innovation diffusion theory has become a basis of thousands of researches and literatures.

Rogers' theory identified five categories of people based on their likeliness to adopt innovation. These 5 categories are Innovators, Early adopters, Early majority, Late majority and laggards. The theory also identified five stages for innovation diffusion which are categorized as knowledge, persuasion, decision, implementation, and confirmation. (Rogers, 2005), (Doyle, Garrett and Currie, 2014)

The most important part of the theory which falls under this research concern is the perception of innovation diffusion. According to Rogers (2005), there are five attributes to each innovative idea which impacts individual acceptance or rejection of the idea in question. (Doyle, Garrett and Currie, 2014). These five attributes are the relative advantage, the compatibility, the trial-ability, the complexity and the observability (Rogers, 2005) (Refer to Figure 6 below). These five attributes are further defined as follows:

I. Relative advantage:

The relative advantage is the added value that the innovative idea offers compared to the existing system that is in place. As per the theory, innovative ideas are likely to be more welcomed, accepted and implemented if they are proven to be adding value and providing advantages compared to the existing method. So there is a positive relationship between the relative advantage of an innovative idea and its rate of positive perception and acceptance (Rogers, 2005)

II. Compatibility :

Innovation is more likely to be accepted if it is in line with existing needs, values, requirements, and regulations. If there are compatibility and incompliance issues with the existing rules and codes, the social system will be reluctant to adopt or support the innovation. This shows that there is a positive relationship between the compatibility of innovative ideas their acceptance (Rogers, 2005).

III. Complexity:

There is a negative relationship between the complexity of innovation and its rate of adoption. Innovative ideas that are perceived as complex and difficult to deal with are most likely to be avoided by individuals and organizations (Rogers, 2005).

IV. Trial-ability:

Any new idea which could be tried at a relatively low cost and small scale will be more accepted and readily welcomed by members of society. This shows that there is a positive relationship between trial-ability of the innovative idea and its acceptance rate is positive (Rogers, 2005).

V. Observability:

The innovation diffusion theory states that innovation is likely to be accepted and adopted more readily if the results and output of this innovation process will be visible and tangible. Hence, the relationship between the adoption rate of innovation and observability of the results is positive. (Rogers, 2005)

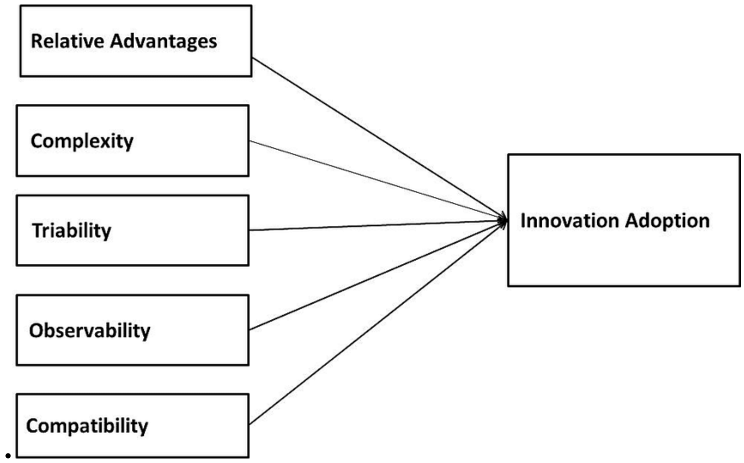

Figure.6: Innovation diffusion theory, Roger, 1983

(Nehemiah, Osden and Pako, 2017)

2.5. Perception of 3D printing in the UAE's construction market

In this section, further literature will be explored to identify the factors which may assess 3D printing technology in the construction industry against one or more of the diffusion attributes explained in section 2.2. The focus, however, will be on the factors which have to do with the application of the technology within the context of the construction market of the UAE.

2.5.1. Relative advantage factors

The following factors have been identified in various literatures as critical factors for the application of 3D printing technology in the construction market of the UAE.

2.5.1.1. Printing speed

The reduction in the time taken for construction projects by implementing this idea has been foreseen as one of the greatest advantages of the application of 3D printing technology in the construction industry (Lim et al., 2012), (Le et al., 2012). Tumbleston et al. (2015) have highlighted printing speed key as the key factor to shorten the duration of the printing process. This speed, however, should not be improved by compromising the quality of the resolution.

2.5.1.2. Machine mobility

Nerella et al. (2016) showed the importance of bringing the printing process on site and highlighted how that can cause a much-needed reduction in required resources and time required for the completion of a project. They have confirmed that doing the printing job on site is directly and positively affecting the acceptance of field experts as doing so is not only proving its economic viability, but also shows how the new system has a proven technological advantage compared to the traditional system.

Perkins and Skitmore, (2015) conducted a comparison between the three main methods described in section 1.3 above. They highlighted the possibility of printing buildings on-site as the primary advantage of the contour crafting method over the other two methods which ends up reducing construction costs by 30% especially in case of non-uniform design buildings (Pegna, 2007). Several other authors, too, encouraged that the other 2 methods could be developed further for on-site processing as well (Lim et al., 2012).

Looking at this point in the context of the construction market of the UAE, the shortage of skilled manpower and the lack of harmony between various cultures within worksites has been identified as a major risk causing construction delay (Ren, Atout, and Jones, J., 2008). This solution will, ultimately, reduce the dependency on the human factor and will add value to 3D printing technology compared to traditional method.

2.5.1.3. Contractor & Consultant BIM capabilities

The role of computers in the construction process is increasing day by day through the design and execution process. With that said, Building Information Modeling (BIM), is the key driver in success in the construction industry today (Elmualim and Gilder, 2014), but for success, key market players (contactor & Consultant) should be very well equipped and prepared for that (Singh, Gu and Wang,2011).

Accordingly, contractor and consultant BIM capability will be a critical contributor for the success of 3D printing application (Foy and Shahbodaghlou, 2015).

2.5.1.4. Printing Resolution

Printing resolution is an important factor which is strongly associated with printing speed (Tumbleston et al., 2015), but it was found to be more related to compliance with existing esthetic values as well as standards and regulations related to tolerance. As researchers and scientists always focused on higher resolution printers (Wong, Kaufui and Aldo Hernandez, 2012), Cali et al., (2012) discussed in their research the relationship between the 3D printing resolution and object function, and they concluded that low-resolution objects may not function properly which may be a disadvantage of the technology in addition to being a compatibility concern.

2.5.1.5. Material Local Availability

In a report about the sustainability assessment of the Gulf region, Sabie, Pitts, and Nicholls (2014) have indicated that the availability of local construction material is among the greatest weaknesses for the Gulf region countries in order to comply with the sustainability requirements.

In line with mandatory requirements of compliance with local green building codes like Dubai Green Building codes and Estidama in Abu Dhabi (Small and Mazrooei, 2016), any construction method that utilizes locally available materials in the country will be more readily accepted comparing to others (Balasubramanian, 2014) as that will fall under compliance and compatibility as well as under the relative advantage category in Roger theory.

2.5.1.6. Sustainability

Sustainability has been considered as a major output of construction innovation (Xue et al., 2014). Sustainability is also one of the key features that could be obtained from deploying 3D printing technology in the construction field (Faludi et al., 2015). The main concept of sustainability in the additive manufacturing technology is the minimization of construction waste. (Bos et al., 2016). In addition to waste reduction, Bhatia (2015) highlighted other sustainability features of 3D printing technology along with the project life cycle, which could be seen in terms of more energy efficient designs, as well as eliminating the needs of double handling, storage yards, and inventories. Additionally, this could also help introduce a new concept of logistics which eliminates the unsustainable long-distance shipping.

The sustainability feature of 3D printing technology will support technology acceptance by enhancing its relative advantages compared to conventional methods, as well as the compatibility with the existing green building rules (Balasubramanian, 2014).

2.5.1.7. Design defect detection

Straub (2015) has highlighted design defect detection as one of the main challenges facing 3D printing technology application. He has highlighted the importance of early detection of design flaws by the computer system controlling the printing process, and even suggested that the computer should either be able to correct the error or at least alert the user for the design error before of the start of the printing process.

Wang et al (2014) stated that 3D printing technology should make use of the advantage of being a computer-based process, so the computer should be utilized to assess and to optimize the design though certain programmed algorithms.

Arayici et al., (2011) examined the link between 3D printing and the “Building Information Modeling” (BIM) and they have found that BIM is strongly invited to team up with 3D printing technology in construction since they are both based on computer models. Additionally, 3D printing technology could make use of BIM capability in conflict detection and design model coordination. This will support the relative advantage of the technology, increase its compatibility, and reduce its complexity.

2.5.1.8. HSE concerns

Health, safety, & environmental aspects (HSE) have been identified by literature as critical factors impacting the success of the construction industry in general (Khosravi and Afshari, 2011). A study conducted by Faludi et al. (2015) aiming to conduct a comparison between 3D printing technology versus the conventional manufacturing process on a lifetime cycle analysis concluded that the impact of 3D printing on the HSE aspects could be more or less than the impact of the conventional method which is dependent on the application methodology itself.

On the other hand, 3D printing is being promoted as a revolution of construction safety due to the tremendous reduction of human workers that are involved in the process (Bos et al., 2016). Such an aspect will be have high importance in the UAE construction market which is greatly concerned with construction's HSE aspects and standards (Shibani, Saidani, and Alhajeri, 2013).

2.5.2. Compatibility factors

The following factors have been identified in literature as critical factors for the application of 3D printing in the UAE construction market. These factors are mainly concerned with material & process compatibility with the market requirement, local regulations, and codes:

2.5.2.1. Software compatibility

Software acts as the communication tool between the computer (where the design will be made) and the printer (where the building blocks for the actual building will be generated). Compatibility is not only important between various software for design, but compatibility between individual software and printer software is also essential for the success of the process (Foy and Shahbodaghlou, 2015). Latteur et al. (2015) highlighted that the process of designing the model in various BIM software and then translating the data involved into understandable instructions the printer requires specific printing software. And since there are many software involved in this process, compatibility between all of them is imperative to ensure the preservation of contained data, and to avoid any data loss during model immigration. (Kaner, 2008).

2.5.2.2. Accuracy and tolerance

Accuracy of the printed job and tolerance of deviation from the original design during the printing process have been identified by Conner et al. (2014) as some of the most important factors that decision makers need to take in consideration while they are to implement the technology, as well as during the selection process of the most suitable method to be used.

The concepts of accuracy and tolerance are of utmost importance for off-site printing and in case of partial print and further assembly, because in this case – similar to the precast construction process – poor accuracy and high tolerance could lead to a process failure, or unaccepted quality and nonconformance (Kim et al., 2015).

A detailed research dedicated on the cost of quality in construction project in the UAE was conducted by Abdelsalam and Gad, (2009) in which they highlighted that the UAE market - and the market of Dubai in particular - is featured for quality projects. Accordingly, projects that don’t comply with market quality standards will not be accepted.

2.5.2.3. Collaboration platform

Huge amounts of digital data exchange in new and modern construction schemes which rely on 3D modeling and BIM will require an adequate collaboration and data exchange platform (Singh, Gu and Wang, 2011). This is described by Moser et al. (2011) as “project management cockpit”, due to its importance to gain the control over the project as a whole including all its different stakeholders.

Such collaboration platforms are essential for 3D printing in construction projects due to the fact that multiple industries are involved in a single project (Xue et al., 2014). This is particularly true in the case of the construction market of the UAE where collaboration has been identified by El-Saboni, Aouad and Sabouni, (2009) as a key success factor of construction success due to the market’s characteristics of being based on international teams.

2.5.2.4. Material Strength

Tensile and compressive strength of 3D printing materials are two of the main factors affecting the success of technology application in the construction industry (Le et al., 2012). Following international standards, materials used in the construction industry are required to pass several compression and tension tests in order to prove their compatibility and to be deemed fit for use in projects (Farina et al., 2016). Several studies have also focused on development of a material that could have high value of compressive and flexural strength,. It is found documented in some literature that the strength could reach up to 107 MPa for compressive and 11 MPa for flexural tests (Le et al., 2012). The research also highlighted the variation of material strength based on the testing direction (parallel to the printing plan, or perpendicular) and it was recommended to take that factor in consideration during the design process.

Bos et al. (2016) have listed the printed concrete's compressive and tensile strength as the main challenge affecting the acceptance of this technology. This especially holds true with the absence of steel reinforcement since there will be higher amounts of loads - the weight of which will need to be borne by the concrete alone.

Material strength was one of the major constraints during the design of the office of the future project in the UAE. This was primarily because the design of the structure needed to adopt the post tension strategy since the material in use was not able to comply with the Dubai municipality's regulations without doing so. (Ben-Ner and Siemsen, 2017).

Here, it is also important to highlight the other constraints associated with material strength as stated by Perrot, Rangeard and Pierre, (2015). Increasing material strength always comes in the way of the material's workability and flow-ability that is required for the material to be extruded from the machine. It is also imperative to set out the material as quickly as possible after it is extruded from the machine in order to ensure that the printed material can start contributing to the structure and supporting next layers.

2.5.2.5. Suitability of Selected Method

Various printing method have been discussed in Section 1.3 above. Each method explained has its own strength and value, as well as different advantages and disadvantages. Selection of the right method, therefore, depends on the purpose of application and is crucial for the success of 3D printing technology in the construction industry (Foy and Shahbodaghlou, 2015), Selection of a suitable printing method is subject to various criteria which will mainly be related to the design, function, and location of the building. Lim et al. (2012) have listed the advantages and disadvantages of each method along with methods that would be suitable and compatible for a number of different types of projects.

2.5.2.6. Custom made design for 3D printing

Gosselin et al., (2016) conducted research on developing a large-scale 3D printing machine that uses ultra-high performance concrete as a printing ink. The importance of the complementary relationship between the design and the printing process was strongly emphasized in the research.

Perrot, Rangeard and Pierre (2015) also conducted a study which focused on developing high strength printing concrete. This study, too, recommended that there should be a customized design for the 3D printing process in order to achieve optimum application results.

2.5.2.7. Academia-industry cooperation

Academia-industry cooperation has been considered a crucial factor for the success of innovation in the construction industry. Xue et al., (2014) have made this conclusion after a critical review of various literature concerned with innovation in the construction industry such as Dulaimi et al., (2002), Slaughter, (1998) and Aouad et al., (2010).

In another study focusing on innovation in the construction market of the UAE done by Al Hallami, Van Horne and Huang, (2013), it was suggested to maximize the role of university-based R&D institutes, backed by governmental efforts, in order to maximize the efficiency and effectiveness of technological innovation in the UAE market. The case study used to verify that hypothesis was for a local construction project. It could, however, be concluded that the above factor is applicable on construction innovation in the UAE as a whole.

2.5.2.8. Knowledge sharing

Limitations pertaining to knowledge and experience have been identified as key barriers for the development of the construction industry in the UAE- especially from the aspect of innovation and new technology projects (Muhammad, M.R.R., 2015), (Balasubramanian, 2012). Knowledge sharing is an essential factor for non-conventional projects to spread the lessons learned and to promote the cooperative spirit which is very vital for project success (Balasubramanian, 2012).

2.5.2.9. Availability of process standards

Blind (2012) has studied the influence of local codes and regulations on innovation development in the UAE market. His study indicated that local codes and regulations as a process standard have a strong influence on the degree of innovation development. This influence is conditional to the existence of the process standard itself as well as the degree of suitability within the parameters of the targeted type of innovation. (Al-Ansari, Y.D.Y., 2014). This factor is, therefore, of particular interest especially when it comes to 3D printing as the innovative process currently suffers due to the absence of proper and specific process standards (Foy and Shahbodaghlou, 2015).

2.5.3. Trial-ability factors

The following factors have been identified in literature as critical factors for the application of 3D printing in the construction market of the UAE. These factors are what give key market players the ability to try and test new technologies before widespread application.

2.5.3.1. Leadership style.

Since the adoption of innovative solutions is a decision which will have a direct impact on the business of the organization adopting it, the leadership style of the organization’s top and middle management is a key contributor for the implementation of the solutions and their success (Alsalami, 2012). In multicultural countries like the UAE, leadership style plays a great role in organizational commitment and success. (Ismail et al, 2011).

2.5.3.2. Flexible scale of application

Wu, Wang, and Wang, (2016) have discussed the potential scale of application for 3D printing within the construction industry. They have highlighted that the products in the construction industry are vary dramatically in scale. Accordingly, any technology that needs to be adopted should tend to this scale of variation. They have concluded this fact as a limitation for 3D printing technology today due to machine size. In other words, no single machine can fit all scales at the moment which is why the variation of demands can prove to be problematic at the current stage.

The scale of application is also related to the printing method (Lim et al. 2012) which has been discussed earlier in section 1.3. Bos et al., (2016) in their critical review for the application of 3D printing technology in construction highlighted the link between the application scale and the printing strategy. The whole building could either be completely built at once, or it could be built in parts and assembled afterwards. Additionally, the building could either be printed on site or off-site. From the research, it could be concluded that every strategy and method requires a different type of printer. Since a multipurpose and multiscale printer has not yet been developed, the technology has a drawback when compared to the traditional method that has been in use for projects in the construction industry. This drawback also affects the relative advantage of 3D printing technology and its trail-ability.

2.5.3.3. Initial cost sharing

The financial aspect of the application of 3D printing technology within the construction industry has been examined by Foy and

Shahbodaghlou (2015). Although the study was focused on small scale applications, it remains valid on large scale applications as well. It was concluded through cost analysis that utilizing the technology will add value to all industry stakeholders, and that the initial cost of development and application should be shared by all beneficiaries.

In another research done by Faridi, & El-Sayegh, (2006) aiming to identify the factors for the delay of construction projects in the UAE, the financial factor has come among the list of the top ten reasons. Initial cost-sharing between contractor and employer could, therefore, play an essential role to facilitate the trial-ability of the new technology and could contribute to widespread application.

2.5.3.4. Enforcement

Enforcement has been considered a major step in the path of the growth in innovation in a newly developed market like that of the UAE (Al-Ansari, Y.D.Y., 2014). When it comes to the construction industry, enforcement has an even higher importance for the promotion of innovation and the application of technological ideas considering that the industry is conservative and reluctant to innovation. (Xue et al., 2014). Blind (2012) in his research has investigated the influence of local codes and regulations in innovation enforcement and it was found to be have a strong association.

2.5.3.5. Encouragement

Motivation of market key players through various reward systems and recognition schemes is a positive factor impacting innovation development in the UAE market (Al Hallami, Van Horne and Huang, 2013). This was also agreed by Al-Ansari, Y.D.Y., (2014) and was highlighted as a good practice to promote the growth of innovation in the local market of the UAE.

2.5.3.6. Alignment of business strategy with government innovation policy

The UAE government is an innovation-oriented government (Al-Khouri, A.M., 2012). Innovative concepts form the core of the government’s vision and policies. (Schilirò, 2015). The organizations that target a successful business in UAE need to align their business strategy with the government's innovation strategy (Miniaoui, H. and Schilirò, D., 2016). With the announcement of the government policy for 3D printing deployment in the local market till the year 2030 (Emirates 24|7, 2017), this factor has become even more crucial for the widespread application of the technology in the local market.

2.5.3.7. Budget allocation for R&D within financial plans

Innovation projects are a product of extensive research and development (Alinaitwe et al, 2007). Availability of funds for R&D works within organizations and in the government budget will facilitate and expedite the process, and will positively contribute to the promotion, widespread use, and success of the 3D printing process in UAE's construction projects (Bygballe and Ingemansson, 2014).

2.5.4. Complexity factors

The following factors have been identified in literature as critical factors for the application of 3D printing in the UAE's construction market. These factors are related to the level of complexity of the technology and the ability of users to deal with the technology without extensive and costly training procedures.

2.5.4.1. Cross Industries Cooperation

The application of 3D printing technology in the construction industry is an output of merged efforts of different industries. It has been described as a "disruptive technology "(Kothman and Faber, 2016) - a term that is generally used for technologies which are able to generate a huge impact on market. At the same time, however, one of the major characteristics of such disruptive technologies is that they never come from a single entity, and they usually integrate efforts from different specialties to generate new technology (Manyika 2013). In the case of the 3D printing technology, specialists from IT firms, manufacturing, supply chain, construction specialists, architects, structural engineers and many others needed to work hand in hand to develop the technology and the process through which it would be implemented (Kothman and Faber, 2016).

Cooperation and coordination between various industry fields will ensure that the new technology will meet its objectives and will be compatible with various needs in addition to supporting trail-ability in the research stage (Xue et al., 2014).

2.5.4.2. User interface

For any innovation that involves human-computer interaction, the software user interface is a key challenge for creativity and success of the innovation (Shneiderman, 2000). Since 3D printing technology is a computer-based innovation, the complexity of the user interface of the printing software will have a direct influence on the user's ability to interact with the technology. (Foy and Shahbodaghlou, 2015).

2.5.4.3. New procurement systems

Innovative procurement systems have been identified as critical for innovation development in UAE market in a study made by Al-Ansari, Y.D.Y. (2014). This factor has immense importance especially when it comes to the application of 3D printing technology in the construction industry in the UAE as the role of specialist suppliers became more critical and essential for the success of the process (Foy and Shahbodaghlou, 2015), Blayse and Manley (2004) also identified the procurement system as one of the key influencers for construction innovation in the UAE.

2.5.5. Observability factors

The following factors have been identified in literature as critical factors for the application of 3D printing in the UAE construction market. These factors are concerned with the observability of the innovation and public's accessibility to the associated information which can promote the technology's popularity:

2.5.5.1. Media and Publication

A critical review study conducted by Peres, Muller, and Mahajan (2010) on the impact of media and publication on innovative products' growth and success has revealed that development in media and publication in the social media era has greatly impacted the diffusion of new and innovative products. The role of the different media channels has proven its significant impact on orienting the public's view and direction in the whole world, with a very specific emphasis on the Arab world (Cottle, 2011)

2.5.5.2. Location of the project

Porter and Stern (2001) have worked out an imperial study to investigate the relationship between innovative projects and their geographic location. The study found that location is a key success factor for innovation diffusion, especially in the UAE. The project location was also found to have a major impact on the project time and cost deviation from the original plan (Faridi and El-Sayegh, 2006).

2.5.5.3. Public accessibility

Martin and Scott (2000) have identified that the absence of public support is a key reason for innovation failure, and in order to gain further public support for the project, the public should be able to access the project. Stewart-Weeks and Kastelle (2015) also highlighted that the innovation targeting public sector is very sensitive to public critics, and it can succeed or fail based on public perception. Granting the public accessibility is, therefore, a critical factor for the public to form their impression and support the success of the project.

2.5.5.4. Application scale

The scale of application of 3D printing dramatically varies from very small scale as in the case of medical procedures, to a very large scale as in construction industry. Large scale application of the technology in the construction industry, however, is acting positively to grab massive audiences (Buswell et al., 2007), (Gosselin et al., 2016)

2.5.5.5. Product visual quality

The visual quality of 3D printed buildings is another attribute related to the printing resolution factor explained above in section 2.3.1.4 (Tumbleston et al., 2015). In addition to the compatibility impact discussed above, the visual quality of the final product will also impact the customers' satisfaction and acceptance (Berman, 2013)

2.5.6. Summary of the identified factors

Table 1 below summarizes the findings of the critical factors impacting the application of 3D printing technology in the UAE's construction market.

No	Factor	Factor	Reference
1	Relative advantage	Printing Speed	(Lim et al., 2012), (Le et al., 2012), (Tumbleston et al., 2015), (Ben-Ner and Siemsen, 2017).
2		Machine mobility	(Nerella et al. 2016), (Perkins and Skitmore, 2015), (Pegna, 2007), (Lim et al., 2012), (Ren, Atout, and Jones, J., 2008),
3		Contractor & Consultant BIM capabilities	(Foy and Shahbodaghlou,2015),(Singh, Gu and Wang,2011), (Elmualim and Gilder, 2014).
4		Printing resolution	(Tumbleston et al., 2015), (Wong, Kaufui and Aldo Hernandez,2012), (Calì et al., 2012)
5		Material Local Availability	(Sabie, Pitts, and Nicholls 2014), (Small and Mazrooei, 2016), (Balasubramanian, 2014),
6		Sustainability	(Bhatia, 2015), (Faludi et al., 2015), (Xue et al., 2014), (Bos et al., 2016), (Balasubramanian, 2014).
7		Design defect detection	(Straub, 2015), (Wang et al., 2014), (Arayici et al., 2011)
8		Method HSE Impact	(Khosravi and Afshari, 2011), (Faludi et al., 2015), (Bos et al., 2016), (Shibani, Saidani, and Alhajeri, 2013)
9	Compatibility	Software Compatibility	(Foy and Shahbodaghlou,2015), (Latteur et al. 2015), (Kaner, 2008).
10		Accuracy and tolerance	(Conner et al., 2014), (Kim et al., 2015), (Abdelsalam and Gad, 2009)
11		Material Health concerns	(Faludi et al., 2015), (Bos et al., 2016), (Khosravi and Afshari, 2011), (Shibani, Saidani, and Alhajeri, 2013)
12		Collaboration platform	(Singh, Gu and Wang), (Moser et al., 2011), (Xue et al., 2014), (El-Saboni, Aouad and Sabouni, 2009)
13		Material Strength	(Farina et al., 2016), (Le et al., 2012), (Lim et al., 2012), (Lim et al., 2011), (Bos et al., 2016), (Perrot, Rangeard and Pierre, 2015), (Ben-Ner and Siemsen, 2017).
14		method Suitability	(Foy and Shahbodaghlou,2015), (Lim et al. 2012)
15		Customized design	(Gosselin et al., 2016), (Perrot, Rangeard and Pierre, 2015)
16		Academia-industry cooperation	(Xue et al., 2014) (Dulaimi et al., 2002), (Slaughter, 1998),(Aouad et al., 2010), (Al Hallami, Van Horne and Huang, 2013)
17		Knowledge sharing	(Abdallah, Khalil, and Divine, 2012), (Muhammad, M.R.R., 2015), (Balasubramanian, 2012).
18		Regulations and codes	(Blind, 2012), (Foy and Shahbodaghlou, 2015), (Manyika, et al., 2013), (Al-Ansari, Y.D.Y., 2014).
19	Trial-ability	Leadership style	(Alsalami, 2012), (Ismail et al, 2011).
20		Availability of Process standards	(Foy and Shahbodaghlou,2015), (Al Hallami, Van Horne and Huang, 2013)
21		scale of	(Wu, Wang and Wang, 2016), (Lim et al. 2012)

		application	(Bos et al., 2016)
22		Initial cost sharing	(Foy and Shahbodaghlou,2015) , (Faridi, & El-Sayegh, 2006)
23		Enforcement	(Blind, 2012), (Xue et al., 2014), (Al-Ansari, Y.D.Y., 2014).
24		Encouragement	(Al Hallami, Van Horne and Huang, 2013), (Al-Ansari, Y.D.Y., 2014).
25		Strategy alignment with government policy	(Al-Khouri, A.M., 2012), (Al-Jundi, 2012), (Schilirò, 2013). .(Schilirò, 2015), (Miniaoui and Schilirò, 2016)
26		Budget allocation for R&D within financial plans	(Alinaitwe et al, 2007), (Bygballe and Ingemansson, 2014), (Blayse and Manley, 2004) (Schilirò, 2015), (Aouad, Ozorhon and Abbott, 2010), (Manley, 2008), (Muscio, Quaglione and Vallanti, 2013).
27	Complexity	Cross Industries Corporation	(Kothman and Faber, 2016), (Manyika 2013). (Xue et al., 2014)
28		method Suitability	(Foy and Shahbodaghlou,2015), (Lim et al. 2012)
29		User interface	(Foy and Shahbodaghlou,2015), (Shneiderman, 2000)
30		Innovative procurement	(Foy and Shahbodaghlou, 2015), (Blayse and Manley, 2004), (Abuelmaatti, and Ahmed, 2014), (Akintoye, Goulding and Zawdie, 2012), (Albaloushi and Skitmore, 2008), (Al-Ansari, Y.D.Y., 2014),
31	Observability	Media and Publication	(Cottle, 2011), (Peres, Muller and Mahajan, 2010)
32		Location	(Porter and Stern, 2001), (Faridi and El-Sayegh, 2006)
33		Public accessibility	(Martin and Scott, 2000), (Stewart-Weeks and Kastelle, 2015)
34		Product visual quality.	(Tumbleston et al., 2015), (Berman, 2013)

Table 1: 3D Printing Key success factors

2.6. Measurement of the success of construction projects

Several papers have been concerned with the development of an instrument to measure the success of a project, and to develop criteria to be used as a scale to judge whether the project has succeeded or failed. The following factors have been identified and repeated in literature as project success measurement factors:

2.6.1. Project efficiency

Project efficiency is considered as the first dimension to measure project success (Müller and Jugdev, 2012). This was also agreed by (Shenhar et al., 2001) while elaborating the understanding of project efficiency further in two major areas: meeting the project's predefined budget, and the planned time schedule.

2.6.2. Impact on the customer

The impact on the customer is a very sensitive measure for the project success especially in the case of innovative projects and new products (Gruner and Homburg, 2000). Many researches have been concerned with market orientation and preparation to accept innovation. (Abdullah Saeed A and Aimin, 2015) & (Nelson Villaverde Chavez, 2015). Several items had been found in literature as a component for the impact on the customer and are summarized below in Table 2

2.6.3. Business success

Projects are generally executed as part of an organization's portfolio which form the organization's business case (Meskendahl, 2010). Success of projects is, therefore, directly linked to the success of the business case (Coulon et al., 2009). Elements and components for business success factor are identified from various literatures as summarized in Table 2 below.

2.6.4. Preparing for the future

Preparing for the future is a project success dimension which mainly measures the project impact on all the stakeholders on a long-term basis (Shenhar et al., 2001). This concept is strongly applicable with innovation projects, as innovation is an opportunity for future (Gu, 2005).

No	Factor	Factor	Reference

1	Project efficiency	Meeting schedule goals	(Müller and Jugdev, 2012), (Shenhar et al., 2001), (Mir and Pinnington, 2014), (Shrnhur, ,Levy and Dvir, 1997), (Serrador and Turner, 2015), (Freeman and Beale,1992), (Atkinson, 1999)
2		Meeting budget goals	
3	Impact on the customer	Meeting functional performance	(Abdullah saeed A and Aimin, 2015), (Nelson Villaverde Chavez, 2015), (Gruner and Homburg, 2000), (Müller and Jugdev, 2012), (Shenhar et al., 2001), (Mir and Pinnington, 2014), (Shrnhur, ,Levy and Dvir, 1997), (Carvalho, Patah and de Souza Bido, 2015) (Baccarini, 1999).
4		Meeting technical specifications	
5		Fulfilling customer needs	
6		Customer satisfaction	
7	Business success	Commercial success	(Shrnhur, ,Levy and Dvir, 1997), (Dvir, Raz and Shenhar, 2003), (Freeman and Beale,1992), (Meskendahl, 2010), (Coulon et al., 2009).
8		Creating a large market share	
9	Preparing for the future	Creating a new market	(Shrnhur, ,Levy and Dvir, 1997), (Shenhar et al., 2001), (Nelson, 2005), (Meskendahl, 2010), (Atkinson, 1999), (Al-Tmeemy et al,2011)
10		Creating a new product line	
11		Developing a new technology	

Table 2: project success measurement factors

2.7. Summary

Literature review has been conducted following the study logic & structure. Firstly, the literature review has explained how the application of 3D printing technology in the construction field is seen as construction innovation. Next, the relation between the acceptance of this innovation and its successful application has been investigated. Lastly, the methodology of choosing innovation diffusion theory as a framework and guideline to identify acceptance factors which may impact the success of the application of 3D printing technology in the UAE construction market has been demonstrated and validated through the literature with a brief on the theoretical concept and its background.

Furthermore, following the five attributes of on innovation diffusion theory, a total of thirty four factors have been identified as critical factors impacting the success of the application of the technology., These factors have been summarized in Table 1 in section 2.5 above which will be taken in further study as the independent variable (IV).

On the other hand, the literature review had been extended to identify the proper instruments to measure the project success. According to literature, four major components can be considered as a scale to measure the success of the project, which in total contain eleven items. Those items have been summarized in Table 2 in section 2.6, and will be taken further in the study as the dependent variable.

The findings of this chapter are also taken for further processing and understanding in the next chapter in order to conclude the study's hypothesis and conceptual framework.

3. CONCEPTUAL FRAME WORK

3.1. Introduction

An intense literature review has been conducted to identify the critical diffusion factors of 3D printing technology application in the construction projects, impacting the success of the construction projects that utilize the technology within the context of the UAE construction market. It was assumed that the five attributes of innovation diffusion identified by Roger would act as the critical factors for the successful application of 3D technology. Literature has been critically examined to identify components of the five attributes namely the relative advantage, the compatibility, the trial-ability, the complexity and the observability. Literature also been examined to identify the project success measurement dimension, and according to the finding, four dimensions were identified which are the project efficiency, the impact on customer, the business success, and preparations for the future.

3.2. Development of Hypotheses

According to the literature findings, it is anticipated to find an evident influence of each of the identified critical factors of the application of 3D printing on the success of the construction projects in the UAE. Also, it is anticipated that all those factors combined will work together in the same direction of influence on the project's success. Furthermore, the integration of all those factors acting together at the same time will lead to a higher level of influence compared to each factor individually with a highly evident significance.

3.3. Null Hypotheses

Development of null hypotheses is a common statistical procedure in academic researches. When the study expects the existence of a relationship between two variables, the study should assume the "nonexistence" of the relationship as a null hypotheses, and work on proving the relationship between the variables at high significance which should not be less than 95% of the population. Once this relationship is proved, the null hypothesis will be rejected, and the alternative hypothesis will be accepted and confirmed. (Frick, 1996)

According to the above and through the findings of the literature review in the previous section, the following general null hypothesis is proposed for this study

Null hypothesis H_o: *3D printing technology diffusion factors are not influencing the technology's successful application in the UAE construction market.*

The above null hypothesis is against the literature finding, and the scope of this research on chapter 4 & 5 is to support the study's suggestion to reject this null hypothesis.

Since the literature review finding suggests that the 3D diffusion factor is influencing the success of the application of 3D printing in the UAE construction market and following the attributes of the diffusing theory, the study would suggest that 3D printing's critical diffusion factor will have a significant influence on the success of 3D printing technology on the macro level (all factors combined together) and on the micro level (each factor group individually).

The study also anticipates that the influence of the integrated factors together will be stronger than the influence of each factor cluster individually.

This suggestion can be phrased in further detailed null hypothesis as the following:

Null Hypothesis $H_0$1(a – e):"*Success of the application of 3D printing technology in construction projects in the UAE is not influenced by a) the level of value added by 3D printing technology in the project compared to the traditional method, b) the degree of technology compatibility with the local industry standard. c) the ability to try & test the technology, d) the level of complexity of 3D printing technology, e) the level of application observability."*

Null Hypothesis $H_0$2:"*the diffusion of the 3D printing technology has no influence on the success of the application of the technology"*

Null Hypothesis $H_0$3*:" the integration of all critical diffusion factors of the 3D printing technology has the same influence on the success of 3D printed applications in the UAE's construction projects compared to each factor's influence individually"*

3.4. Conceptual Model

The rejection of the above identified null hypotheses will lead to confirmation and acceptance of the alternative hypotheses which the exact opposites of the null hypotheses. The alternative hypotheses are presented graphically in the following conceptual model in figure 7

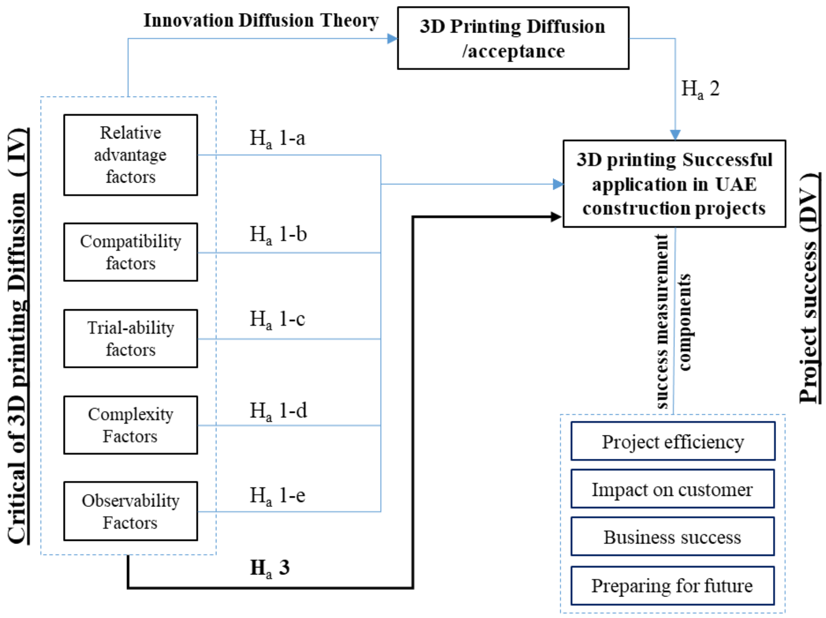

Figure 7: Theoretical conceptual Model

3.5. Summary

In this chapter, the finding of the literature review has been organized in a logical form in line with the study objectives in order to conclude the theoretical hypotheses which will be the subject for further verification. Since the literature review process indicated the possibility of the existence of strong relationship between the acceptance of 3D printing technology by field specialists and the success of the application of the technology within the construction market of the UAE, the study's null hypothesis has been proposed to assume absence of any influence between 3D diffusion and the success of the projects where the technology was applied. As per the null hypothesis, this influence has been denied to happen in two levels. The first level of these is the global level, i.e. between the technology diffusion and the project success in a broad view, and the other level is on factor cluster level as the null hypothesis suggested the absence of the influence between each cluster of the 3D printing diffusion factors (following the categorization of the innovation diffusion theory).

As the study also predicted that the strength of influence between 3D printing diffusion factors on the project success will be higher in value when those factors are integrated together compared to the individual act of the each factor group isolated, this assumption has been challenged through an additional null hypothesis which denies the difference in influence strength between the influence of the each factor's cluster individually.

All of these null hypotheses are rejected based on the literature review's findings and alternative hypotheses which have contradictory and opposing contents. The confirmation of the relationship and the influence of the above discussed variables are suggested to be accepted.

This finding has been graphically represented in the conceptual model (frame work) shown in figure 7 above.

These findings and their hypothetical representation has been concluded based on the literature finding, however, they will be subject to further investigation and verification in the next chapter of the study.

4. RESEARCH METHODOLOGY

4.1. Introduction

As the previous chapters suggested hypotheses and had a suggested conceptual model based on literature findings, this chapter aims to demonstrate the methodology chosen to verify and validate the study's suggestion. It will explain in detail how to assess the relationship between the identified independent variable which are the diffusion factors of 3D printing, and the dependent variable which is the success of the 3D printed construction projects in the UAE market.

This chapter explains how the research is structured, and how the required data for verification is collected. It also provides the required information on why particular methods were found to be the most suitable approaches for this study, how the chosen test had been designed, and how the results of the analysis could represent a static and realistic finding which could be taken with enough confidence and reliability as a proper instrument to assess the literature finding.

4.2. Research methods

For academic studies, there are three main methodologies for research and theoretical investigation. Those three methodologies are the qualitative analysis, quantitative analysis, and the mixed approach.

The qualitative analysis is a methodology of research. It is a detailed analysis targeting to explain human interaction and involvement with surrounding variables on a real basis on how it actually happens (Polkinghorne, 2005). In such analyses, all possible questions which will lead to a deep understanding of the motivation and justification behind the respondent's belief, perception or action will questioned and the answers will be deeply analyzed (Barnham, 2015).

Quantitative analysis, on the other hand, is a form of statistical analysis for a large number of responses on a particular set of questions related to identified variables. It should, however, be noted that the selected samples should act as a good representation for the actual larger number of population. (Mugenda, 1999). In the quantitative approach, it is believed that the representation of the collected data from the participated samples will be applicable on the whole population, as that should explain the public beliefs and also translate their behavior as well as help to understand the mental modes of the whole population. (Barnham, 2015)

As the name suggests, the mixed method is a combined approach which utilizes the approaches that were explained earlier (Mugenda, 1999). This method can be used in cases when it can be problematic to rely on a single approach for the study, or when the study is related to phenomena which may have a severe contrast in individual perceptions and interests, making it difficult to justify individual behaviors based on a single method. (Johnson et al., 2007; Venkatesh, Brown & Bala, 2013).

4.3. Selection of quantitative methodology:

Based on the explanation of the different research methods above, the quantitative approach was found to be the most suitable approach for this study due the following reasons:

- Since the study objective is to examine the static relationship between two variables which are the 3D critical diffusion factors as an independent variables, and the success of the 3D printing projects as the dependent variable, the quantitative approach will be more suitable to assess the existence of the relationship and assess its nature and strength. This is because quantitative approach justifies the beliefs of a positivist pattern, which indicates that certain actions can be justified through unbiased facts. (Firestone, W.A., 1987)
- The quantitative approach is found to be used widely in similar studies concerned with analyzing critical factors influencing certain variable changes, – particularly those that are concerned with the public opinion on innovation and new technology. Examples include Sivas's and Dwyer (2000), Hong and Kim, (2002), and many others.
- Since one variable of the studies is concerned with social acceptance of the certain variable (3D printing technology) in a certain field (construction industry) within a certain geographical context (UAE market), collecting actual data from a wide range of field experts within the study context will ensure the accuracy of the study and the suitability of the study objectives. Using a participatory approach for a random samples within certain

qualification criteria over large and representing national sampling was also found to be more applicable with the quantitative approach.(Garbarino, and Holland, 2009)

- As the 3D printing application is a new technology in the local market and is not yet fully diffused, it is essential to avoid individual bias towards or against that particular technology to maintain the integrity of the study. The quantitative approach with larger samples was, therefore, found to be more suitable to minimize the impact of bias from the participants or the researcher (Smith and Noble, 2014).
- The study aims to confirm and use 3D printing's critical diffusion factor as a predictor of the success of 3D printing application. Using the quantitative approach and analyzing the data collected through a computer based statistics software will result in accurate analytical and numerical results for reliability, validity, and significance which would not be possible with the qualitative approach (Smith and Noble, 2014).

Based on the above justification, the quantitative approach has been selected for this research, and to ensure the logic integrity, a systematic approach for the study's methodology has been adopted following the model proposed by Flynn. Et al. (1990). In the approach, a theoretical belief is built based on a critical literature review, which is subject to verification. Then, the quantitative approach has been selected to conduct verification, and for that purpose a survey questionnaire is selected for the data collection. The next step was to select the samples which could represent the targeted population while designing the questionnaire itself to collect the exact required data supporting the research objectives. The collected data is then to be processed in a specialized software, and the results are to be examined against the theoretical framework assumed in the first step. Finally, reports will be generated to conclude the output of the research. The afore-mentioned systematic approach can be summarized in the diagram in figure 8 below:

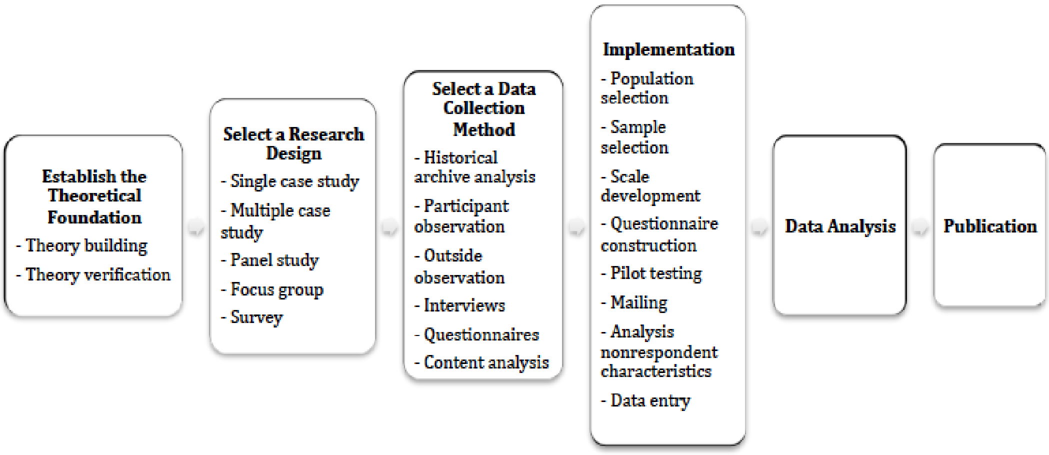

Figure 8: Conducting empirical research using a systematic approach

(Flynn et al. 1990, p. 254)

4.4. Research philosophical assumption:

This section will clarify the philosophical assumption of the research just like the last section focused on the justification of the selection of the quantitative approach for the research.

Any academic or social research in its ontological and epistemological aspects will be guided by a main belief, known as the research paradigm (Guba & Linclon, 1994). The research paradigm is a means of investigating pre-assumed social phenomena in a trial to realize the core of its motivation and the way of its behavior. (Creswell, 1994). As a common good practice in research, the researchers should have a deep understanding and sound realization of the research paradigm and the philosophical assumptions of the research in order to be able to get a proper resolution of the researched topics. These philosophical assumptions are defined through three main terminologies namely positivism, interpretivism, and pragmatism, and are used as guidelines for research design. In order to conclude an adequate reply to the questions of the research, it is imperative to throughly understand the required evidences and the techniques that could be used to explain the results along with complete awareness of the existing barriers and limitations of the research (Easterby-Smith, Thorpe & Lowe, 2002).

This study is categorized under social science research as it related to the public acceptance of technology and public perception of project success. Additionally, the objective of this research is to define certain aspects to promote a positive reaction towards 3D printing technology within the construction industry and

UAE’s local market. Positivism and interpretivism are considered as the main related philosophical aspects as in the case of the majority of social science researches (Easterby-Smith, Thorpe & Lowe, 2002).

Positivism is the approach of natural sciences that utilizes a combination of logics - which are the deductive rigid logic of an existing proven theory along with a specific empirical experience from social user's behavior - in order to form an opinion about pre-assumed hypotheses that can help to predict future behavior (Yates, 2003). Interpretivisim (also known as social constructionism) is the methodology that is concerned with the exploration of why there is a difference in the human view and internal perception without focusing on the external factors that may impact their reactions. (Easterby-Smith, Thorpe & Lowe, 2002).

Interpretivisim is considered as an inductive approach because it methodically examines social behaviours through a comprehensive understanding of individuals in a normal array in order to reach a common philosophy or rule on how individuals generate and sustain their social domains (Yates, 2003). At this point, it is also important to note that philosophically concluded queries regularly come before research method questions. Accordingly, academics need to decide which philosophical position they will follow, and choose between the positivism and interpretivism approaches (Guba & Linclon ,1994). Adoption of multiple research philosophies were also found to be acceptable according to Later, Saunders et al. (2016), ultimately leading to the occurrence of pragmatism. This concept exists when the study does not get anchored to a certain research philosophy (Saunders et al., 2016).

Since this research is grounded on a proven theory (innovation diffusion theory) and relies on collecting individual opinions on the occurrence of identified diffusion factors - in addition to assessing the level of project success following identified measurement factors which has been agreed upon in former published literature and verified via previous researches - the positivism approach is more appropriate for this study. Positivism will not only facilitate the application of a structured approach that utilizes the quantitative approach, but will also be more appropriate for statistical analysis of the collected data.

4.5. Research Approach

Based on the discussion on philosophical assumptions as demonstrated in the previous section, the selected approach will provide guidance to the study to properly choose the form of the data and research methodology required to respond to the study question.

Table 3 below explains the difference between the deductive approach and the inductive approach. According to that comparison, it is evident that the deductive approach is more related to the quantitative methodology, and the inductive approach is more appropriate with the qualitative methodology. This conclusion can also be explained by the nature of the quantitative approach. Since the methodology is dealing with large amount of collected statistical data, and utilizes statistical techniques for analysis (Tsang, 2014), this is more matching with the nature of the positivism (deduction) approach and also deploys statistical formulas to analyse a huge amount of observations

Deduction emphasises	Induction emphasises
Scientific principles	Gaining an understanding of the meaning of humans attach to events
Moving from theory to data	A close understanding of the research context
The need to explain casual relationships between variables	The collection of qualitative data
The collection of quantitative data	A more flexible structure to permit changes of research emphasis as the research progresses
The application of controls to insure validity of data	A realization that the researcher is part of the research process
The operationalization od concepts to insure clarity of definition	Less concern with the need to generalize
A highly structured approach	
Researcher independence of what is being researched	
The necessity of selecting samples of sufficient size in order to generalize conclusions	

Table 3: deductive and inductive research approaches

(Adapted form Saunders et al. 2016, p. 145).

Based on all the above, the deductive technique is more valid for this study as the study's objective is to identify critical diffusion factors of 3D printing which will in an increase of the success of the application of 3D printing technology construction projects in the UAE with the adoption of a designed research approach based on the innovation diffusion theory. Since the study will be self-governing and free from any observed public bias, the results have been collected in quantitative approach; the sample is selected based on a valid criteria to represent the targeted population; and the research is mainly targeting to test a relationship between two variables, the deduction approach has been selected for the study.

4.6. Research design and process

Understanding investigation methodologies supports in making the right choice of the study plan and approaches (Easterby-Smith et al., 2012). Study design requires a set of coherent decision-making options that can be selected rationally by academics. Noting the aims of the research, these choices can comprise the element of study, the time limits, the outline of the research, and the degree of intervention of the researcher (Cavana et al., 2001). Accordingly, it is crucial to (1) define the elements of the study, (2) investigate the connected operational definitions, and (3) translate the suggestions into hypotheses (Forza, 2002).

In this study, item 1, the element of study, is the application of 3D printing technology in construction projects in the UAE. This item has selected for the critical diffusion factor aspect, and to assess the success of the projects utilizing the technology.

Items 2 and 3 those have been covered in chapter 3.

4.7. Survey questionnaire

This chapter of the research focuses on the verification of the concluded hypotheses in the previous chapter using the quantitative approach by analyzing the data collected via a designed survey questionnaire (Appendix 1).

Survey questionnaires are the most common method for quantitative research (Forza, 2010). While there are pros and cons for every known research tool, survey questionnaires have been chosen as the data collecting tool for this research for the following reasons: **To overcome geographical and cultural barriers:** Since the number of targeted participants is limited due to certain reasons, the impact on current location, and the cultural or language fluency should not act further to reduce the number of possible participants. The survey questionnaire can help overcome this problem as the survey can be distributed in form of electronic mail (email) for those who are not currently in the UAE, and it gives them a chance to translate the questions and answer. Additionally, since multiple choice questions does not require high language proficiency to answer (Wright, 2005), the survey questionnaire can be filled out by most people.

- Ease of data analysis, as the study objective is to evaluate the relationship between the variables, and develop formulas to predict the change of the dependent variable based on the independent variable change, it is strongly recommended to rely on clear and numeric data in order to reach a clear determined output. This is another reason why it is best to use the survey questionnaire (Forza, 2010).
- **Privacy of responses:** Since the designed questionnaire is not asking to disclose the personality of the respondents, the privacy of the participants is highly maintained compared to any other method, allowing users to respond to the questions without any pressure and then ensure the accuracy of the response and the avoidance of any misleading answers. This factor could have a high importance in our study in particular as the research topic is somehow related to the government target of the 3D printing application, and some participants may feel more comfortable if their identity remains anonymous (Sills and Song, 2002)

Four sub-processes were involved in the design process of the questionnaire. The first step was to transform the conceptual model into empirical domain. Next, the questionnaire was designed as per the variables and scales. The third step was to conduct the pilot test and validate the test based on the pilot test results after which the, survey was conducted on the broad scale for data analysis, result discussion, and reporting.

It is important to deal with all constrains, chase the required data, maintain sustainability of the approaches, and confirm the viability of the research (Forza, 2010). It is also important to realize that a well-designed survey with clear directions, introduction, and a well-designed set of inquiries with a proper arrangement and answer options can help participants to respond to the questions (Forza, 2010).

After completion of data collection, the results were analysed using the Statistical Package for Social Sciences (SPSS) version 23. This helps in performing initial data analysis like checking the frequency, reliability, correlations & regression.

The details of data testing and results will be explained in detail in the next chapter.
This approach has been chosen and designed to assess the validity and accuracy of the theoretical concluded framework for two reasons. The first reason is validating the actual occurrence of the identified critical factors in the 3D printing projects either in the UAE or similar contexts as an independent variable (IV), and second dimension is measuring the level of project success as a dependent variable (DV). The correlation and influence between both dimensions can be verified and measured by conducting data analysis for the received responses from participants for both dimensions. Furthermore, factors identified by the literature review will be also segregated and shortlisted based on the level of influence in order to reach a conclusion of the real critical factors influencing the success of the 3D printing in the UAE's construction projects. Additionally, since the research is concerned with the application of a new technology within specific industry and specific geographic context, collecting opinions of field experts on said market for a wide range of aspects was found to be adequate as hypothesis verification. Accordingly, as explained in section 4.3 earlier, the quantitative approach using the survey questionnaire is deemed to be the most appropriate method for this research.

The survey has been designed in 3 sections.
The first section aims to collect demographic information and personal data about the participants, along with their educational background and level of experience. This data has been collected to further investigate the research results in case it doesn't match with the hypotheses findings and for any future use of the same collected data.
The second section aims to collect data on the actual occurrence of the critical factors influencing the diffusion of the 3D printing technology in the UAE construction market including direct questions on the identified factors. This section has one question for each factor, grouped in 5 factor clusters based on the innovation diffusion theory. The groups are, therefore, categorized asnrelative advantage, compatibility, trial-ability, complexity and observability. Those factor clusters have been taken as five scales to measure the independent variable of the test.

The third section aims to collect data measuring the success of the 3D printed projects. This also includes factors identified by literature as proven measures of project success. In this section, each factor has a corresponding question, and they have been also grouped in 4 factors cluster based on literature findings. The categories are project efficiency, the impact on customer, business success, and preparing for the future. These factors have been taken as 4 scales to measure the dependent variable of the test.

All the scales utilized in the test have been evaluated using the Likert rating system on five levels starting from "strongly agree" as a representation of the strong occurrence of the factor down to "strongly disagree" which represents the complete absence of the questioned factor.

Since this research is based on a new technology which is not widely spread, the participating candidates have been carefully selected as those who have in any way been involved in 3D printing project execution, design, or research. For the sake of objective clarity, a research brief had been conducted verbally and a brief statement was included in the survey, which includes historical information about the technology and some construction facts about the pioneer project, "office of the future," which were gathered either from literature or trusted public media. Table 4 below summarizes the questionnaire variables and scales

	Independent variable	Dependent variable
Variable to be tested	3D printing critical diffusion factors in UAE construction project	Success of 3D printing construction project in UAE
Number of Factors	Thirty four factors (34)	Eleven (11) factors
Number of factors clusters	Five (5) clusters following innovation diffusion theory	Four (4) clusters following the project success measurement instrument
Number of scales	Five (5) scales , every cluster taken as a scale to be tested individually	One (1) scales, all factors computed together to measure project success

Table 4: summary of the questionnaire variables and scales.

4.8. Sampling and population

The targeted participants for the survey have been selected through a certain criteria with a minimum qualifications to guarantee a minimum level of knowledge with the construction industry in the UAE as well as the application of

3D printing in the construction field. A minimum of three of the four conditions below had to be met for a participant to be deemed eligible for the survey:

- To be well engaged in the construction industry either as contractors, consultants or developers.
- To be very familiar with the UAE construction market
- To be among senior management or decision makers in their organization
- To have basic involvement with 3D printing technology (participants could either be involved through actual 3D printing projects or have participated in certain related tenders or researches related to the technology.)

The questionnaire was then distributed (by means of hard copy mostly and email for some members who were currently remotely located,) and the collected date was input in the SPSS software for further testing.

The questionnaire was distributed to 137 members of which 107 members responded, giving us a response rate of 78.10 % which is considered as acceptable. (Baruch, 1999)

4.9. Pilot Study

Pilot tests have been recommended in literature to be conducted in advance to ensure the suitability of a questionnaire and consistency of responses with study objectives (Muijs, 2004). A pilot test assists the researcher to fine tune the questions and to ensure the alignment of test results with the study aims and objectives. The pilot test is a quality control process for the survey, but it can't be taken as a representing study (Glesne 2011). It also gives indication on the public interest in test topic, and accordingly could justify the topic significance (Glesne, 2011) A pilot test on twenty (20) candidates had been conducted first, with a note to comment on the questions which were not clear to be further elaborated. The result of pilot group was input to the SPSS software for initial testing, and the result were showing a high reliability and correlation for obtained data. Minor changes were recommended for three questions which were addressed in the final version.

4.10. Summary

As the conceptual framework of this study has been concluded in the previous chapter, this chapter was concerned with the verification method used to verify the theoretical finding. Through this chapter, various research methods were explained briefly, and the three main methods of academic and social research were identified as the qualitative approach, the quantitative approach and the mixed approach. The quantitative approach was found to be more appropriate for the study objective, and the rationale behind this has been explained. Besides the research's analytical approach, the philosophical approach of the research had also been explored. As per comparison between different approaches of the philosophical aspect of the research, the positivism (deduction) approach has been selected as it was appropriate for the study's objectives and aims.

Finally, in terms of data collection instruments, the study found that the survey questionnaire was more matching the study merit, and the rationale behind that choice was explained. Additionally, the process of designing the survey and testing its validity through the pilot tests was also demonstrated.

5. DATA ANALAYSIS

5.1. Introduction

As explained in detail in chapter 4, the quantitative research methodology has been selected to verify the concluded hypotheses and conceptual model concluded in chapter 3. The survey questionnaire has been selected as the data collecting instrument and the data collected through the questionnaire is processed through the SPSS software. The test results are demonstrated as they get reported out of the software, and the data processing in this section will start by reporting the demographic analysis.

The data related to gender of participants, their age group, education level, occupation and function of their organization is represented in form of graphical charts.

A set of data tests has also been performed. The first test was the reliability test, which aimed to verify the validity of the collected data and extent to which the data can be trusted and how it provides a good representation of the population. A correlation matrix among the factor clusters of the independent variable (3D printing critical diffusion factor) and the dependent factor clusters (success of 3D printed projects) was also taken into consideration.

After confirming the association between the identified factors either for the IV or the DV, the last step was to assess the influence of the critical diffusion factor of 3D printing on the success of 3D printed projects in order to judge and accept or reject the identified null hypotheses as well as predict the degree of influence which could be used to predict the future change on the success of the 3D printing technology application in construction projects upon the change of the identified 3D printing critical diffusion factors.

Results and outputs from the afore-mentioned tests will be subject for critical investigation in the next chapter to understand the rationale and motivation behind the participants' responses, helping us gain valuable insight and understanding the technology application parameters and public perception towards its application. Through these insights and understanding, it will be possible for us to predict their future performance.

5.2. Descriptive analysis

5.2.1. Demographic information

The demographic details of the participants as following:

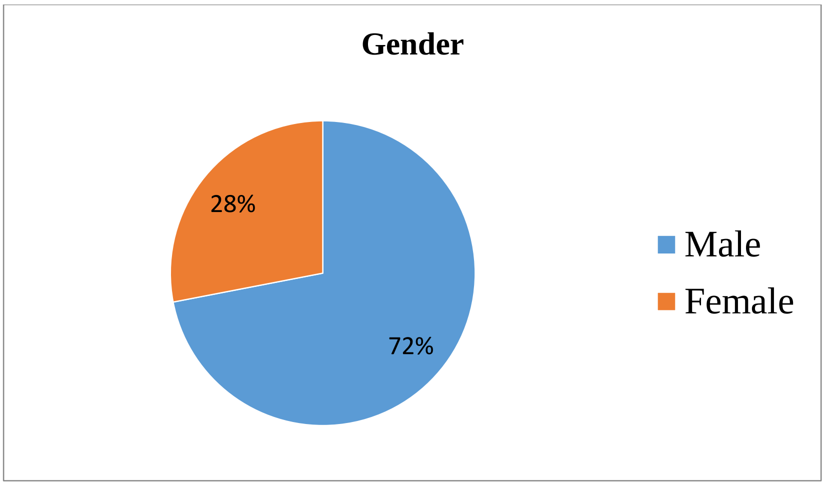

Figure 9: Candidate Male to Female Ratio

As per Figure 9 above, there were 77 male participants (72%) and 30 female participants (28%.)

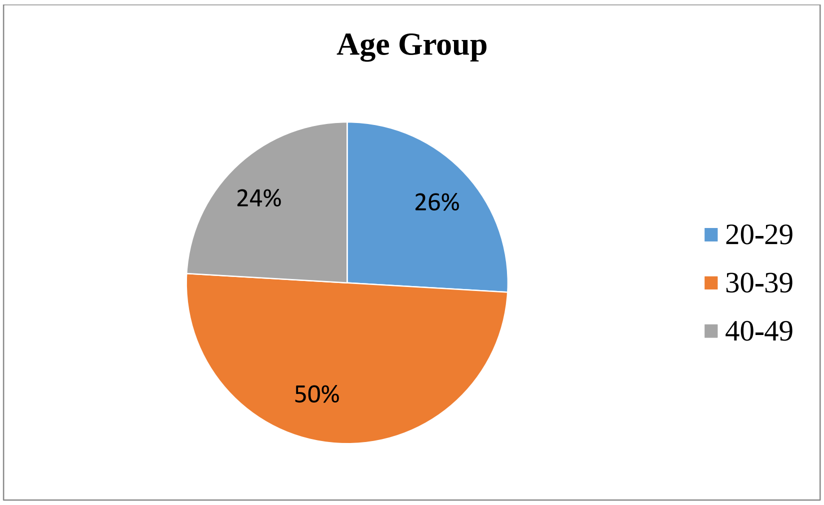

Figure 10: Candidate Age Group Distribution

As per Figure 10 above the majority of participants were in the age group of 30-39, with total number of 54 participants and a percentage of 50%, followed by age group of 20-29 with 28 people and a percentage of 26% and last group are the senior staff in the 40-49 age group with number of 26 participants and a percentage of 24%

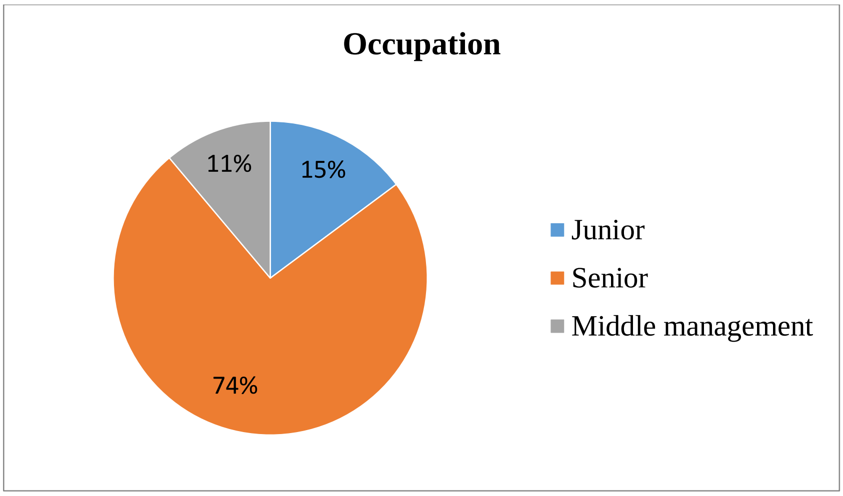

Figure 11: Candidate Occupation Distribution

Figure 11 above represent the participants' roles within their organizations. The majority of the participants were at senior level with a total of 79 participants or 74%, followed by junior levels with a total of 16 participants or 15%. Middle management gave the least responses with a total of 12 participants or 11% of the total number of participants.

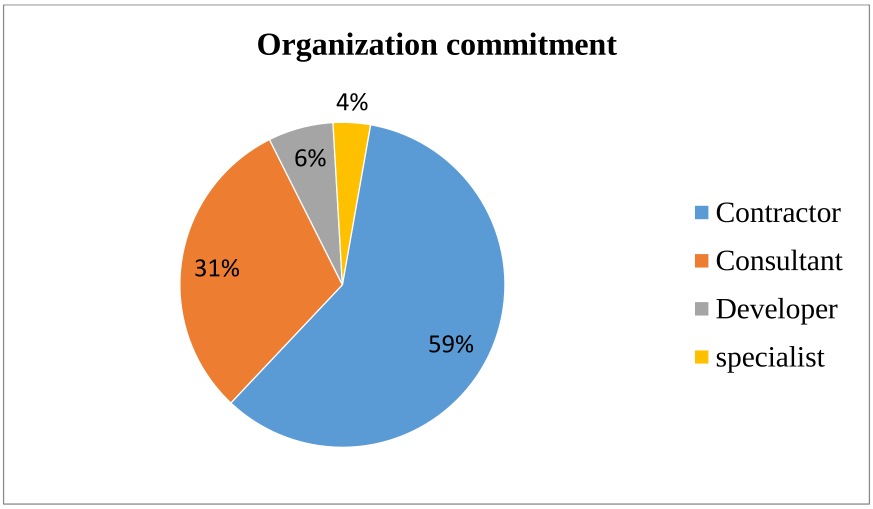

Figure 12: Type of Organization Distribution

Figure 12 above represents the type of organization of the participants. The majority of the participants (59%)were from contractor organizations, followed by consultants (31%), and lastly developers (6%).

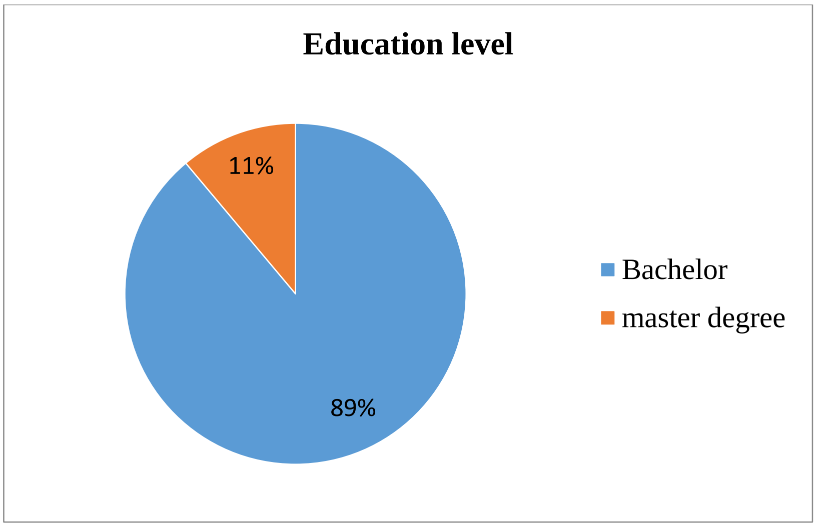

Figure 13: Candidate Education Level

89% of the participants had a bachelor's degree, while 11% of the participants were master's degree holders as per Figure 13 above.

5.2.2. Factors description

This study aims to measure the association and the influence between two main variables. The first variable is the critical diffusion factors of 3D printing which stand in this study as independent variables, and the second variable is the success of 3D printing projects which act in this study as the dependent variable. The sections below will provide descriptive information about both variables and their components

5.2.2.1. Independent variable:

In this study, the independent variable is the critical diffusion factors of 3D printing as explained in detail in section 2.5 above. With literature review, we have concluded thirty four (34) factors as critical diffusion factors, grouped under five factor clusters following the innovation diffusion attributes suggested by the innovation diffusion theory. Those five clusters are the relative advantage, the compatibility, the trial-ability, the complexity, and the observability. The five clusters form five scales to measure the acceptance and diffusion of 3D printing technology in the UAE construction market. Those five scales contain a total of 34 questions, each question representing one factor. The descriptive statistics of those five clusters can be found in table 5 below.

	N	Minimum	Maximum	Mean	Std. Deviation
Relative advantage	107	8.00	31.00	12.1776	3.28465
Compatibility	107	10.00	28.00	15.7290	3.55700
Trial-ability	107	8.00	23.00	12.5234	2.84289
Complexity	107	4.00	15.00	6.4206	2.11926
Observability	107	4.00	14.00	5.9720	2.01625
Valid N (listwise)	107				

Table 5: descriptive statistics for IV factor clusters

- **Relative advantage cluster:**

The relative advantage cluster is the first scale to measure the diffusion of 3D printing technology. Based on a group of factors representing the relative advantage of the technology compared to conventional methods, this cluster contains eight factors, represented by eight questions, inquiring participants' opinions about how every questioned factor contributes to making 3D printing technology more beneficial to construction projects in UAE compared to conventional construction methods. The response of the participants has been rated on the Likert scale and loaded to the SPSS software with a weighting legend ranging from one point to five (5) points. The response representing the strongest agreement weighs one (1) point, and strongest disagreement weighs five (5) points. The expected minimum weight of a participant's response equals eight (8) points which represents absolute agreement, and the maximum weight will equal to forty (40) points which means absolute disagreement. The frequency statistics for the relative advantages as displayed below in figure 14 indicate a high tendency of the participants' responses to agree with that immense value has been added by 3D printing technology compared to the conventional method, as the mean answer weight found to be equal to 12.77 points, and the standard deviation is 3.285 which is closer to minimum value than the maximum value.

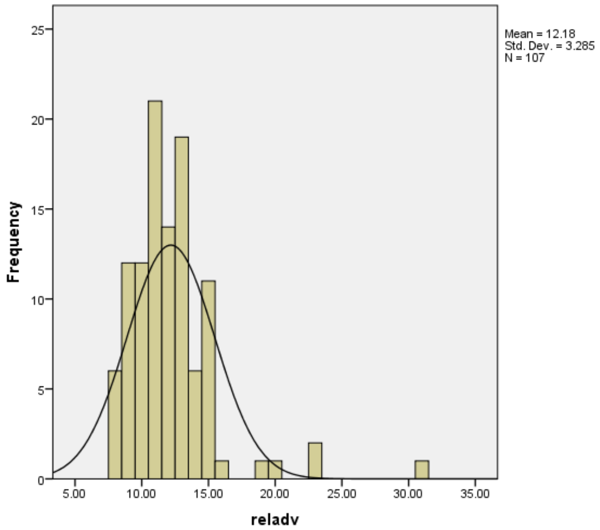

Figure 14: Relative advantage factor cluster frequency

Compatibility cluster:

The compatibility cluster is the second scale to measure the diffusion of the 3D printing technology. Based on a group of factors representing the degree to the 3D printing technology compatibility with the local market regulations and needs, this cluster contains ten (10) factors, represented by ten questions, inquiring participants' opinions about how every questioned factor contributed to confirm the technology compatibility with local market in UAE. The response weighting representing the strongest agreement weighed one (1) point, and strongest disagreement weighed five (5) points. The minimum possible weight of a participants' response would equal ten (10) points which meant absolute agreement, and the maximum weight would equal fifty (50) points which meant absolute disagreement. The frequency statistics for the compatibility cluster as displayed below in figure 15 indicate a high tendency of participants' responses to agree with the high degree of 3D printing technology compatibility, as the mean answer weight was found to be 15.73 points, and the standard deviation is 3.557 which is closer to minimum value than the maximum value.

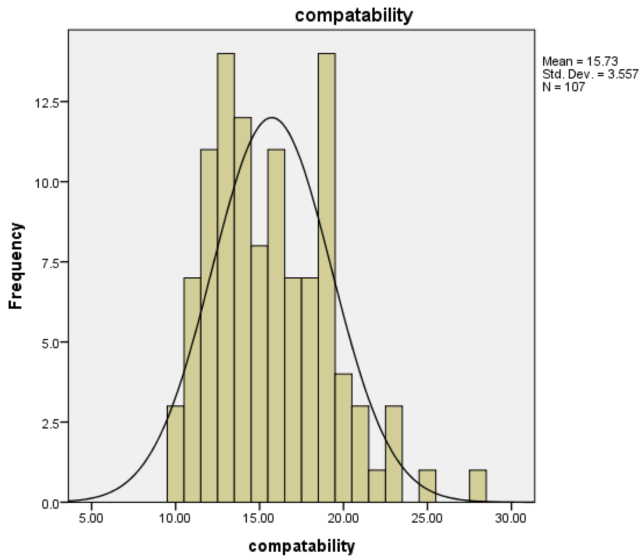

Figure 15: compatibility factor cluster frequency

Trial-ability cluster:

The trail-ability cluster is the third scale to measure the diffusion of the 3D printing technology. Based on a group of factors representing the degree of the possibility to try 3D printing technology in the local market of UAE, this cluster contains eight (8) factors, represented by eight (8) questions, inquiring participants' opinions about how every questioned factor contributes to confirm the technology trial-ability within the local market of UAE. The response representing the strongest agreement weighed one (1) point, and the strongest was represented by five (5) points. The minimum possible weight of a participants' response would be equal to eight (8) points which meant absolute agreement, and the maximum weight would be equal to forty (40) points which meant absolute disagreement. The frequency statistics for the trial-ability cluster as displayed below in figure 16 indicate a high tendency of participant's response to agree with the high degree of 3D printing technology trial-ability, as the mean answer weight was found to be equal to 12.52 points, and the standard deviation is 2.843 which is closer to minimum value than the maximum value.

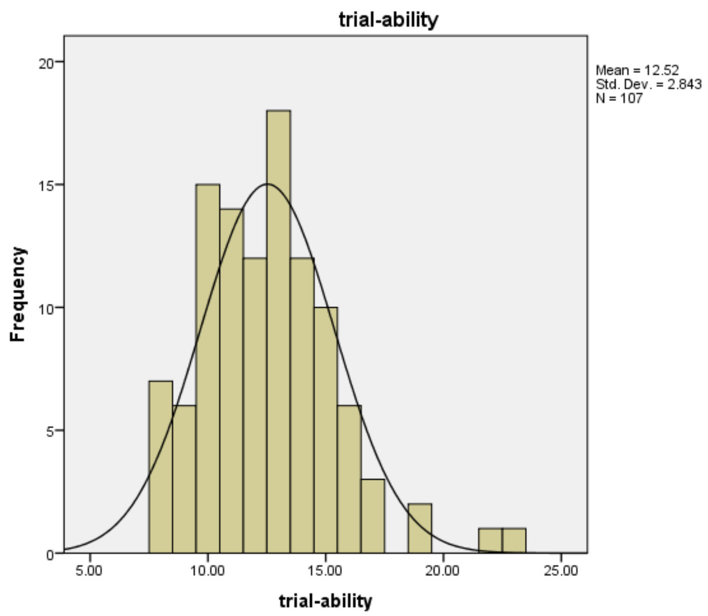

Figure 16: trial-ability factor cluster frequency

Complexity cluster:

The complexity cluster is the forth scale to measure the diffusion of the 3D printing technology. Based on a group of factors representing the degree of the complexity associated with technology in the local market of UAE, this cluster contains four (4) factors, represented by four (4) questions, inquiring participants' opinions about how every questioned factor contributes to simplify technology and make it less complex during its application within the local market of the UAE. The response representing the strongest agreement weighed one (1) point, and strongest disagreement weighed five (5) points. The minimum possible weight of a participants' response will equal four (4) points which mean absolute agreement on technology simplicity, and the maximum weight will equal to twenty (20) points which means absolute disagreement. The frequency statistics for the complexity cluster as displayed below in figure 17 indicated a high tendency of participant's response to agree on the contribution of identified factors to simplify the 3D printing technology, as the mean answer weight was found to be equal to 6.42 points, and the standard deviation is 2.119 which is closer to the minimum possible value than the maximum value.

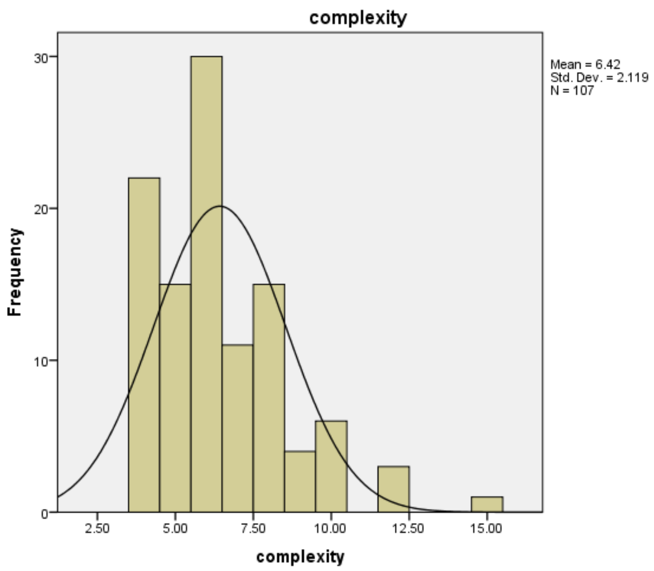

Figure 17: complexity factor cluster frequency

Observability cluster:

The observability cluster is the fifth scale to measure the diffusion of the 3D printing technology. Based on a group of factors acting to make the 3D printing technology visible and observable in the local market of the UAE, this cluster contains four (4) factors, represented by four (4) questions, inquiring participants' opinions about how every questioned factor contributed to increase the observability of the technology in local market of UAE. The response representing the strongest agreement weighed one (1) point, and the strongest disagreement weighed five (5) points. The minimum possible weight of a participant response was four (4) points which meant absolute agreement on technology observability, and the maximum weight was twenty (20) points which meant absolute disagreement. The frequency statistics for the observability cluster as displayed below in figure 18 indicate a high tendency of participant's response to agree on the contribution of identified factors to increase the observability of 3D printing technology, as the mean answer weight was found to be equal to 5.97 points, and the standard deviation was 2.016 which was closer to the minimum possible value than the maximum value.

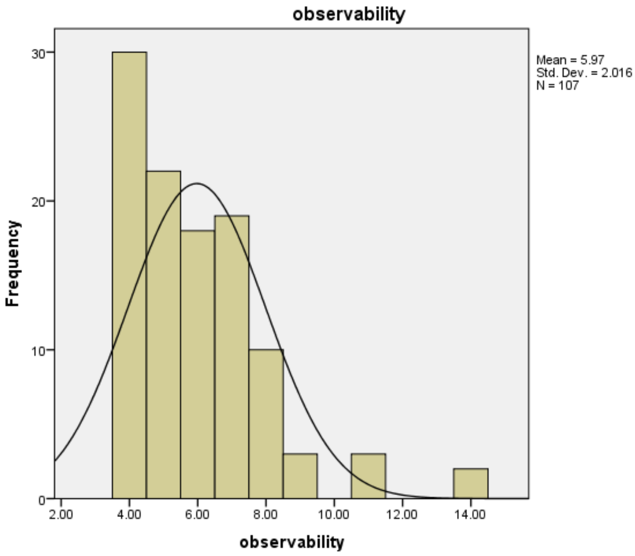

Figure 18: Observability factor cluster frequency

5.2.2.2. Dependent variable:

In this study, the dependent variable is the success of the application of 3D printing technology in the UAE's construction projects, and is measured by measuring the degree of the success of the projects that utilized 3D printing technology.

Project success, as explained in detail in section 2.6 above, is found in literature to be measurable on a scale of four factor clusters that contain eleven factors. Those four clusters are the project efficiency, the impact on customer, business success, and the preparation for the future. As the study objective is to measure the impact of the different diffusion factors of 3D printing technology on the success of construction projects in UAE, all the identified factors of projects success have been taken as one scale containing a total of eleven questions under four clusters, where each question represent one factor. The descriptive statistics of those four clusters can be found in table 6 below.

	N	Minimum	Maximum	Mean	Std. Deviation
project efficiency	107	2.00	8.00	3.0561	1.27258
Impact on Customer	107	4.00	16.00	6.6542	2.54433
business success	107	2.00	7.00	2.8785	.98776
prepare for future	107	3.00	13.00	4.3832	1.42514
Valid N (listwise)	107				

Table 6: descriptive statistics for DV factor clusters

The project success scale contained eleven questions representing eleven identified project success factors and aimed to inquire participants' opinion about how they could assess the degree of each factor's occurrence in order to judge the project success. A Likert scale of five degrees was also used similar to the scale that was used for the independent variable. The response representing the strongest agreement weighed one (1) point, and strongest disagreement weighed by five (5) points. All the identified factors were calculated in one scale together as a global factor representing the dependent variable. The expected minimum weight of a participants' response would be eleven (11) points which meant absolute agreement on project success, and the maximum weight would be fifty five (55) points which meant absolute disagreement. The frequency statistics for dependent variable cluster as displayed in figure 19 below indicates a high tendency of participants' to agree on the success of the 3D printing projects, as the mean answer was found to be equal to 16.97 points, and the standard deviation is 5.251 which is closer to the minimum value than the maximum value

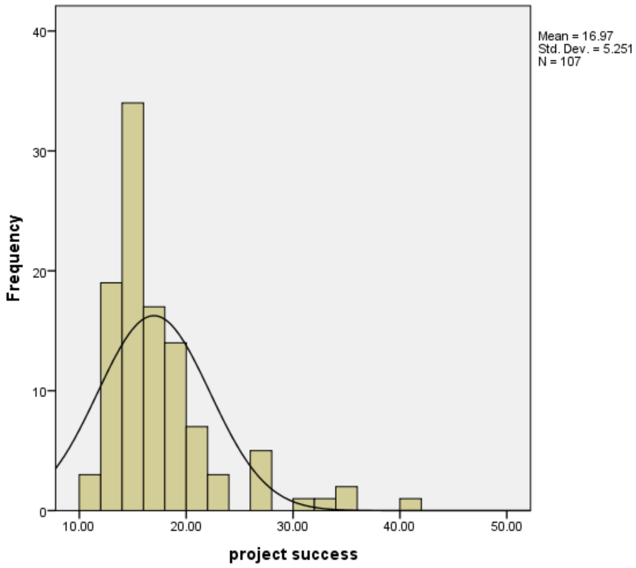

Figure 19: project success frequency

5.3. Reliability Test

The collected data has been tested for its reliability at first stage. Cronbach's alpha test has been used to assess the data internal consistency in three stages:

The first stage was to test each individual cluster of the independent variable. Since there are five factor clusters identified as independent variables, the Cronbach alpha test was conducted five times for reliability. It is important to note that the test was conducted between the factors of each individual cluster.

The test results are populated in Table 7:

The second stage was to test each individual cluster of the dependent variable Since there were four factor clusters identified as dependent variables, the Cronbach alpha test was conducted four times for reliability. Again, each time the test was conducted between the factors of each individual cluster.

The test results are populated in Table 8:

The third stage was to test the global factor for each of the independent variables and the dependent variables

The fourth stage <u>was</u> to test all items together:

The results of both third and fourth stage are represented in table 9 below.

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted	Cronbach's Alpha
Radv1	10.78	9.138	.307	.760	
Radv2	10.67	8.241	.521	.722	
Radv3	10.65	8.342	.465	.733	
Radv4	10.48	8.044	.521	.722	0.796
Radv5	10.69	8.196	.478	.731	
Radv6	10.72	8.732	.458	.735	
Radv7	10.58	8.152	.588	.711	
Radv8	10.67	9.505	.315	.756	
Compat9	14.17	10.915	.410	.682	
Compat10	14.12	9.919	.512	.660	
Compat11	13.53	8.138	.510	.665	
Compat12	14.30	10.230	.556	.659	
Compat13	14.16	10.871	.425	.680	
Compat14	14.10	9.848	.519	.659	0.709
Compat15	14.27	11.935	.125	.719	
Compat16	14.40	11.922	.144	.715	
Compat17	14.27	11.633	.097	.734	
Compat18	14.23	10.388	.470	.670	
Trial19	11.16	6.720	.404	.680	
Trial20	10.86	6.650	.320	.696	
Trial21	10.95	6.819	.302	.699	
Trial22	11.08	6.644	.380	.683	
Trial23	11.00	6.547	.378	.683	0.708
Trial24	10.71	5.774	.467	.664	
Trial25	10.91	5.652	.572	.635	
Trial26	10.99	6.764	.368	.686	
Complex27	4.89	2.591	.619	.720	
Complex28	4.80	2.688	.620	.720	0.786
Complex29	4.79	2.599	.610	.724	
Complex30	4.78	2.949	.525	.766	
Observ31	4.45	2.099	.743	.685	
Observ32	4.43	2.379	.588	.769	0.803
Observ33	4.58	2.642	.553	.782	
Observ34	4.46	2.628	.598	.764	

Table 7: Reliability Statistics using Alpha Method for IV factors

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted	Cronbach's Alpha
Suceffic35	1.36	.439	.640		0.776
Suceffic36	1.70	.551	.640		
Succust37	4.79	3.887	.630	.854	0.860
Succust38	4.91	3.501	.759	.799	
Succust39	5.11	3.931	.733	.812	
Succust40	5.16	3.927	.713	.819	
Sucbiz41	1.25	.247	.552		0.700
Sucbiz42	1.63	.387	.552		
Sucfut43	2.87	1.039	.481	.469	0.628
Sucfut44	2.98	1.075	.385	.607	
Sucfut45	2.92	1.097	.451	.513	

Table 8: Reliability Statistics using Alpha Method for DV factors

The results of the 4 stages of the test are represented in Table 9 below:

Test Stage	Test Subject	Test	Cronbach's Alpha	N of Items
Stage 1	3D diffusion factor clusters (IV)	Relative advantage	.796	8
		Compatibility	.709	10
		trial-ability	.708	8
		complexity	.786	4
		observability	.803	4
Stage 2	project success factor clusters (DV)	project efficiency	.776	2
		Impact on Customer	.860	4
		Business success	.700	2
		future opportunity	.628	3
Stage 3	Global IV	All IV Factors	.878	34
	Global DV	All DV Factors	.897	11
Stage 4	All Factors	All Factors	.925	45

Table 9: Reliability Statistics using Alpha Method.

The data collected passed the first test of reliability, the Cronbach Alpha test. The test was run on every factor cluster individually, then on all items of each variable together, and finally on all items of both variables together. Every individual factor cluster got an alpha value higher than 0.7 which means that it is reliable data according to the details mentioned in the previous chapter. This result also proves internal consistency between all the collected data. (George and Mallery, 2011)

The only exception in the results was in the cluster of "future opportunity" of project success measurement which got a Cronbach alpha value of 0.628. This is beyond the standard acceptance criteria of minimum alpha which states that the value should be 0.7 or more. However, deviation can be explained due to the uncertainties associated with the future of the development of the technology and also the disagreement among the experts on the speed of development of the technology and the time frame required for the technology to mature. (Jiang, Kleer and Piller, 2017)

Furthermore, the test on all the items together has shown a value of 0.925, which is to be classified as Excellent Reliability as per George and Mallery, (2011). This value also reflects very high internal consistency in between the various questioned items according to the high level of consistency between the received responses.

5.4. Correlation.

A Pearson's product-moment correlation was conducted to measure the relationship between the identified critical factors for 3D printing application in the UAE construction market and the success of the projects. The test has been conducted on the cluster level, as well as for the global independent variable factor and the global dependent variable factor.

The test aimed to investigate the following:

- The correlation between clusters within the same variable
- The correlation between dependent variable clusters and independent variable clusters
- The correlation between global factors and the individual clusters of both variables
- The strength of correlation in between the global variables

Colour coding has been used to represent different forms of correlation according to test objectives as indicated above. Yellow shading is used to represent the correlation between clusters within the same variable (either dependent or independent), blue shading is used to represent the correlation between clusters within a variable with clusters another variable, and green shading is used to represent the correlation between both variables' clusters and both variables' global factors. The threshold for correlation realization was marked when the Pearson factor was found to be > 0.3 and the significance was at a minimum of 95%

The result of the Pearson's product-moment correlation test is represented in Table 10 below:

Correlations

		reladv	compat	trial	complex	observ	suceffic	succust	sucbiz	sucfut	globalIV	globalDV
reladv	Pearson	1	.539**	.557**	.527**	.384**	.508**	.602**	.545**	.638**	.868**	.691**
	Sig. (2-tailed)		.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
	N	107	107	107	107	107	107	107	107	107	107	107
compat	Pearson		1	.269**	.486**	.223*	.454**	.580**	.321**	.508**	.757**	.589**
	Sig. (2-tailed)			.005	.000	.021	.000	.000	.001	.000	.000	.000
	N		107	107	107	107	107	107	107	107	107	107
trial	Pearson			1	.214*	.279**	.169	.433**	.305**	.255**	.665**	.378**
	Sig. (2-tailed)				.027	.004	.082	.000	.001	.008	.000	.000
	N			107	107	107	107	107	107	107	107	107
complex	Pearson				1	.312**	.484**	.487**	.516**	.574**	.682**	.606**
	Sig. (2-tailed)					.001	.000	.000	.000	.000	.000	.000
	N				107	107	107	107	107	107	107	107
observ	Pearson					1	.515**	.405**	.391**	.339**	.553**	.486**
	Sig. (2-tailed)						.000	.000	.000	.000	.000	.000
	N					107	107	107	107	107	107	107
suceffic	Pearson						1	.609**	.456**	.576**	.583**	.780**
	Sig. (2-tailed)							.000	.000	.000	.000	.000
	N						107	107	107	107	107	107
succust	Pearson							1	.584**	.648**	.712**	.918**
	Sig. (2-tailed)								.000	.000	.000	.000
	N							107	107	107	107	107
sucbiz	Pearson								1	.590**	.568**	.741**
	Sig. (2-tailed)									.000	.000	.000
	N								107	107	107	107
sucfut	Pearson									1	.653**	.836**
	Sig. (2-tailed)										.000	.000
	N									107	107	107
globalIV	Pearson										1	.771**
	Sig. (2-tailed)											.000
	N										107	107
globalDV	Pearson											1
	Sig. (2-tailed)											
	N											107

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 10: Correlation test for the all factor clusters and global factors

After trusting the reliability of the collected data, in order to challenge the null hypotheses H_0, it was essential to ensure that all items under the test correlate with each other with certain minimum significance. Additionally, any item that proved to have no correlation with any other item from the rest of the factors was to be excluded from the study. By analysing the data from the correlation tests conducted as per the criteria stated in section 5.4 above, and data that was further analysed in Table 10, the following results are reported:

a) There is an association within the 3D diffusion factor clusters (IV factors), as each cluster correlates with at least two other clusters with correlation coefficient higher than 0.3 and a significance higher than 95% (Foster, 2001).

b) There is an association within the project success factor clusters (DV Factors), as each cluster correlates with at least two other clusters with correlation coefficient higher than 0.3 (Norusis, 1992).

c) There is an association between the clusters across both the independent variable and the dependent variable, as each cluster in the 3D diffusion factor cluster is correlating with at least 2 clusters of the project success factor cluster with correlation coefficient higher than 0.3 and vice versa. According to the above, none of the tested factor clusters were found to be subject to exclusion.

d) All the clusters of the independent variable (3D diffusion) are in association with the global dependent variable (project success)

e) All the clusters of the dependent variable (project success) are in association with the global independent variable (3D printing diffusion)

f) The above findings for points (d) and (e) confirm the association between critical diffusion factors of 3D printing and the project success at a significance of higher than 95% percent of the population which supports the rejection of the Null hypothesis H_0 and also the acceptance of the alternative hypotheses H_a1(a-e), H_a2, H_a3. As how it is highlighted in green in Table 10 above, the relative advantage factor has a correlation coefficient of 0.868, p<,005 (alternative hypothesis H_a1a) , the compatibility factor has a value of 0.757, p<,005 (alternative hypothesis H_a1b) the trial-ability factor has a value of 0.0665, p<,005 (alternative hypothesis H_a1c) complexity factor has a value of 0.682, p<,005 (alternative hypothesis H_a1d) and the observability factor has a value of 0.553, p<,005 (alternative hypothesis H_a1e) All the values of correlation significance between the intended variable factors and the dependent factors are positive and below 0.005, which are accepted values and support the existence of the relationship , allowing us to reject the null hypothesis and accept the alternative hypotheses (Foster, 2001).

g) At the global level, the global dependent variable (project success) is in strong association with the global independent variable (3D printing diffusion)/ The tests showed a Pearson's product-moment correlation coefficient of 0.771, and a significance of p=0.000, <0.005 which means that all participants who responded gave similar answers and there was no significant outlier in the global aspect of the study. That finding supported the rejection of the null hypothesis and supported the acceptance of the alternative hypothesis.

h) The finding above is explained by the fact that all the participants highly engaged in the construction industry, and a vast majority of them have both UAE construction market knowledge and 3D printing technology knowledge, either through involvement in real and actual 3D printing projects in UAE, or by participating in certain related tenders or researches.

i) One more reason that could explain the high level of agreement in between the participants is the questionnaire brief, which contained informative data about the technology and about the pioneer 3D printing project in UAE, “the office of the future.” .Since the number of projects for which the technology was applied in the local market is limited, it was healthy for the research to supply the participant with certain information about the technology and the applied project, so they could use such information to compare it to their own experience and knowledge in other projects, and to come up with an answer which is based on facts, reducing any resulting noise that may appear due to absence of relevant information.

j) The above results were found to be in line with the basic framework of the study according to the literature review finding (Tornatzky and Klein, 1982), (Sonnenwald, Maglaughlin, and Whitton, 2001). (Polančič, Heričko and Rozman, 2010).

5.5. Factor deletion

In order to confirm if all the proposed factors were contributing well in the study, the factors were inspected for the possibility of deletion from the reliability and correlation point of view.

From the details in the Cronbach alpha analysis in Table 7 and 8, and through investigating the column of "Cronbach's Alpha if Item Deleted," it was found that for all scales for independent variables and dependent variables, there was no case where a factor significantly impacted the Cronbach alpha negatively. In the test results, the gap between the overall alpha value for each scale, and the value of "Cronbach alpha if item deleted" is very close which is why it was decided to keep all the tested items in all scales after confirmation that no item was eligible for deletion from the reliability point of view.

As explained in section 5.4 above, every identified cluster was found to be correlating with at least one other factor from the same variable, and at least one cluster from the other variable. All clusters were also found to be correlating with the global factor for both dependent and independent variables. This finding also confirms that all of the factors contributed logically towards hypotheses analysis which is why no factors were deleted.

5.6. Regression:

Linear regression test method was chosen to assess the level of influence of each individual factor cluster of the independent variable (3D printing diffusion factor) on the dependent variable (project success). The method was also used to predict the value of expected change of the dependent variable whenever the independent variable got changed.

The test had been conducted in 2 stages:

First stage: Linear regression test was run by assigning each factor of the identified critical factor clusters for the 3D printing application (relative advantage, compatibility, trial-ability, complexity and observability) as an independent variable, and comparing them with the global factor of the project success measurement as the independent variable. The process was repeated with changes in the independent variable each time.

Second stage: Linear regression test was run by assigning the global factor of the 3D printing critical application factors as the independent variable which was tested with the global factor of the project success measurement as the dependent variable. The purpose of the test was to measure the influence of all the identified critical factors of 3D printing application in UAE's construction projects combined on the success of the project, and to predict the change in value of project success corresponding to the change of the critical factors' occurrence.

Test no. 1: relative advantage factors cluster regression with the project success:

The linear regression test has been conducted to predict the change in project success based on the change of diffusion factors identified. As per test results a significant equation was found in the relative advantage cluster as F (1, 105) = 95.907, p<.000 with an R^2 value of 0.447 which represented a static evident regression with a high significance. Additionally, this regression model was a good fit (As per table 11 below).

The unstandardized coefficient of regression for this test, B, was found to be 1.104 and had a constant value of 3.53 (as per Table 12 above). Figure number 20 below is a graphic representation of the regression line between the relative advantage factor cluster as IV and the project success as DV:

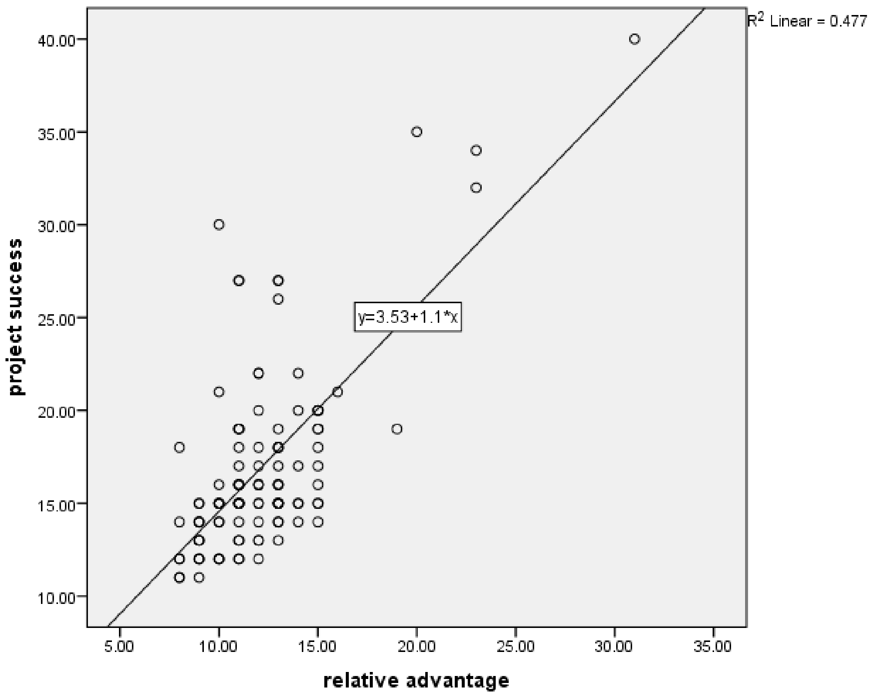

Figure 20: Relative advantage cluster and project success regression

According to the above, the regression line slope equation between the relative advantage and the project success can be written as y = 3.53+1.1 * X which means that the project success increased by 1.1 units for each unit increase in relative advantage factors.

According to the above, the relative advantage is a positive predictor for the project success, with a very high statistically significant predictive capability which proves that it is a good fit.

<u>Test no. 2 : Compatibility factors cluster regression with the project success:</u>

The linear regression test was conducted to predict the change in project success based on the change of diffusion factors identified in the compatibility cluster. As per test results, a significant regression equation was found as F (1, 105) = 55.780, $p<.000$ with an R^2 value of 0.347 which represent a static evident regression with a high significance and the regression model has a high degree of goodness of fit (as per table 11 below), The unstandardized coefficient of regression for this test, B, was found to be 0.87 and had a constant factor of 3.29 (as per table 12 above). Figure Number 21 below is a graphic representation of the regression line between the compatibility factors cluster as IV and the project success as DV.

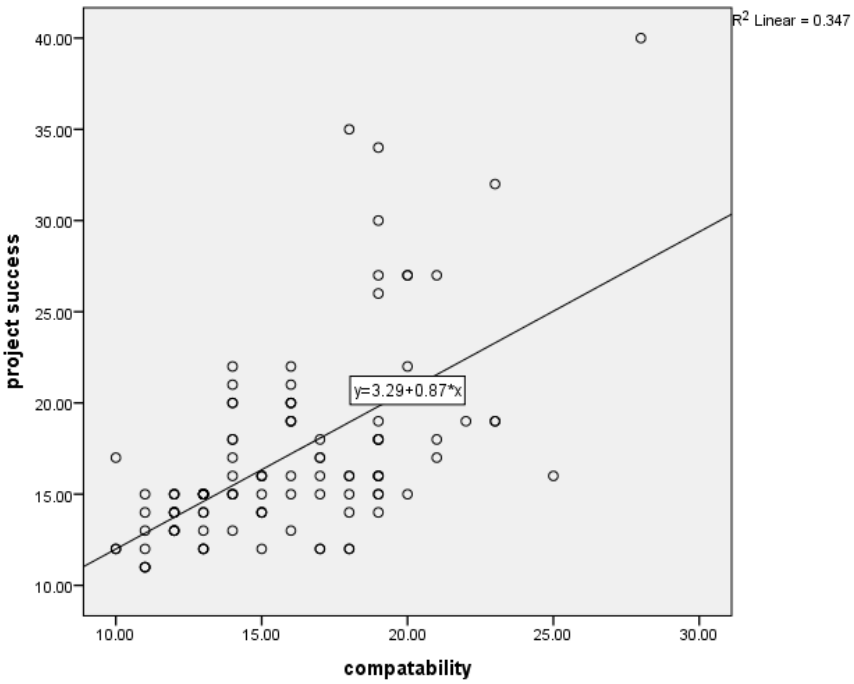

Figure 21: Compatibility cluster and project success regression

According to the above, the regression line slope equation between the relative advantage and the project success can be written as y = 3.29+0.87 * X which means that the project success increased by 0.87 units for each unit increase of relative advantage factors.

According to the above, the compatibility cluster of factors is a positive predictor of the success of a project, with a very high statistically significant predictive capability which proves its goodness of fit.

<u>Test no. 3 : Trial-ability factors cluster regression with the project success:</u>

The linear regression test has been conducted to predict the change in project success based on the change of diffusion factors identified in the compatibility cluster. As per the test results, a significant regression equation was found as F (1, 105) = 55.780, $p<.000$ with an R^2 value of 0.347 representing a static evident regression with high significance and showing that the regression model has a high degree of goodness of fit (as per table 11 below), The unstandardized coefficient of regression for test B was found to be 0.87 with a constant factor of 3.29 (as per table 12 above). Figure Number 21 below is a graphic representation of the regression line between the compatibility factor cluster as IV and the project success as DV.

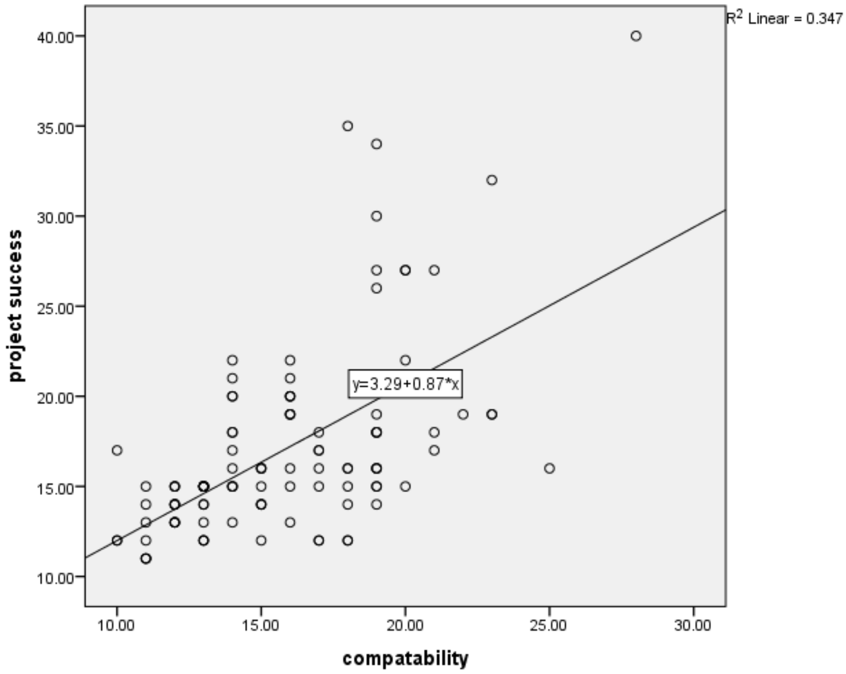

Figure 21: Compatibility cluster and project success regression

According to the above, the regression line slope equation between the relative advantage and the project success can be written as y = 3.29+0.87 * X which means that the project success increased by 0.87 units for each unit increase in relative advantage factors.

According to the above, the compatibility cluster of factors is a positive predictor of project success, with a very high statistically significant predictive capability which proves its goodness to fit.

<u>Test no. 4 : Complexity factors cluster regression with the project success:</u>

The linear regression test was conducted to predict the change in project success based on the change of diffusion factors identified. As per the test results, a significant regression equation was found in the complexity cluster as F (1, 105) =

61.048, *p*<.000 with an R^2 value of 0.368 representing a statistically evident regression with a high significance and shows that the regression model has a high degree of goodness of fit (As per table 11 below), The unstandardized coefficient of regression for test B was found to be 1.502 with a constant factor of 7.33 (as per table 12 above).

According to the above, the regression line slope equation between the trial-ability and project success can be written as y = 7.33+1.5 * X which means that project success increased by 1.5 units for each unit increase in complexity factors.

According to the above, the complexity cluster of factors is a positive predictor for the success of a project, with a very high statistically significant predictive capability which proves its goodness to fit.

Figure Number 23 below is a graphic representation of the regression line between the complexity factor cluster as IV and the project success as DV

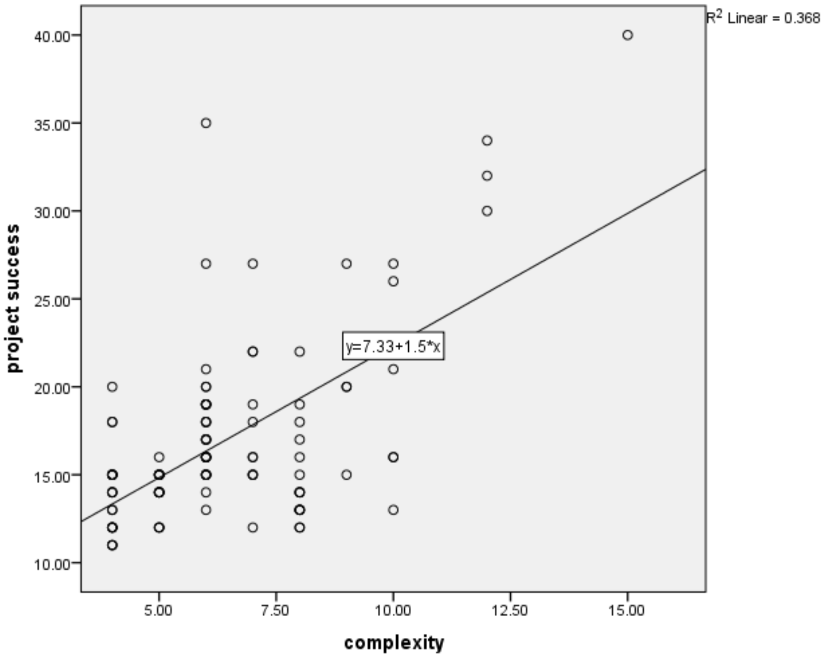

Figure 23: Complexity cluster and project success regression

<u>Test no. 5 : Observability factors cluster regression with the project success:</u>

The linear regression test has been conducted to predict the change in project success based on the change of diffusion factors identified in the observability cluster. As per the test results, a significant regression equation was found as F (1, 105) = 32.545, *p*<.000 with an R^2 value of 0.237 which represents a statistically evident regression with a high significance, and shows that the regression model has a high degree goodness of fit (as per table 11 below). The unstandardized coefficient of regression for test B was found to be 1.27 and has a constant factor of 9.41 (as per table 12 above).

According to the above, the regression line slope equation between the observability and the project success can be written as y = 9.41+1.27 * X which means that the project success increased by 0.87 units for each unit increase in observability factors.

According to the above, the trial-ability cluster of factors is a positive predictor for project success, with a very high statistically significant predictive capability which proves its goodness to fit.

Figure Number 24 below is a graphic representation of the regression line between the observability factors cluster as IV and the project success as DV

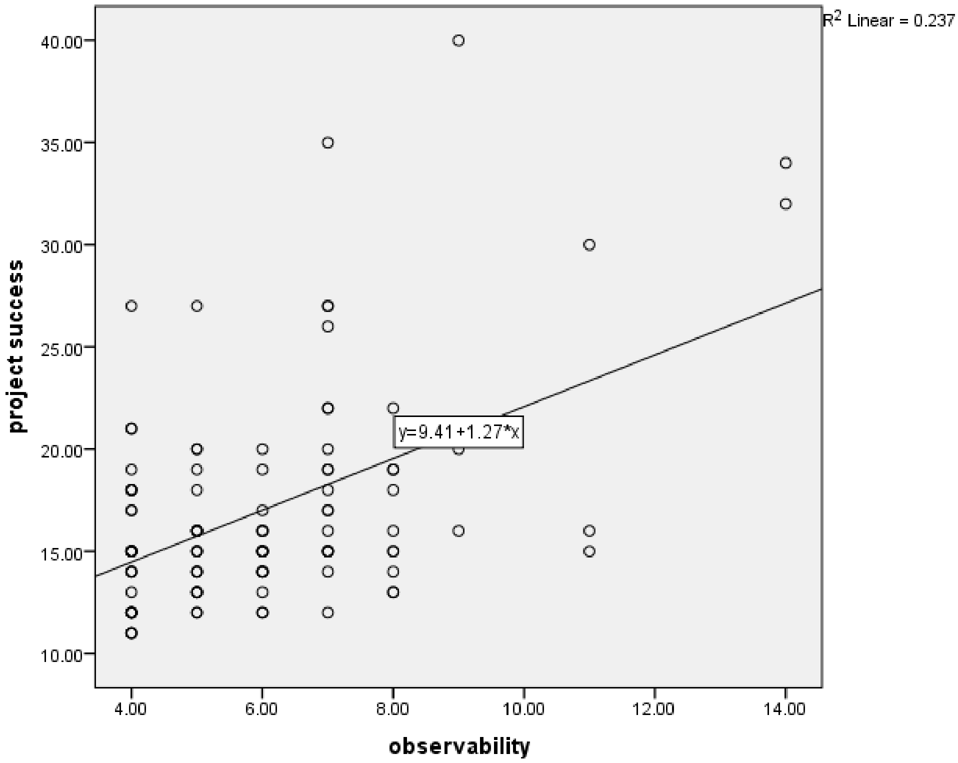

Figure 24: Observability cluster and project success regression

<u>Test no. 6 : Critical diffusion factors (global IV) regression with the project success :</u>

In order to confirm the influence of the all the identified factors combined on the variation of the project success ratio, the linear regression test has been conducted to predict the change in project success based on the change of diffusion factors identified in the five clusters of 3D printing diffusion factors combined. As per the test results, a significant regression equation was found as F (1, 105) = 153.621 $p<.000$ with an R^2 value of 0.594 which represents a statistically evident regression with high significance and shows that the regression model has a high degree of goodness of fit (as per table 11 below). The unstandardized coefficient of regression for test B was found to be 0.401 with a constant factor of -4.42 (as per table 12 above).

According to the above, the regression line slope equation between the observability and the project success can be written as y = -4.42+0.4 * X, which means that project success increased by 0.4 units for each unit increase in diffusion factors.

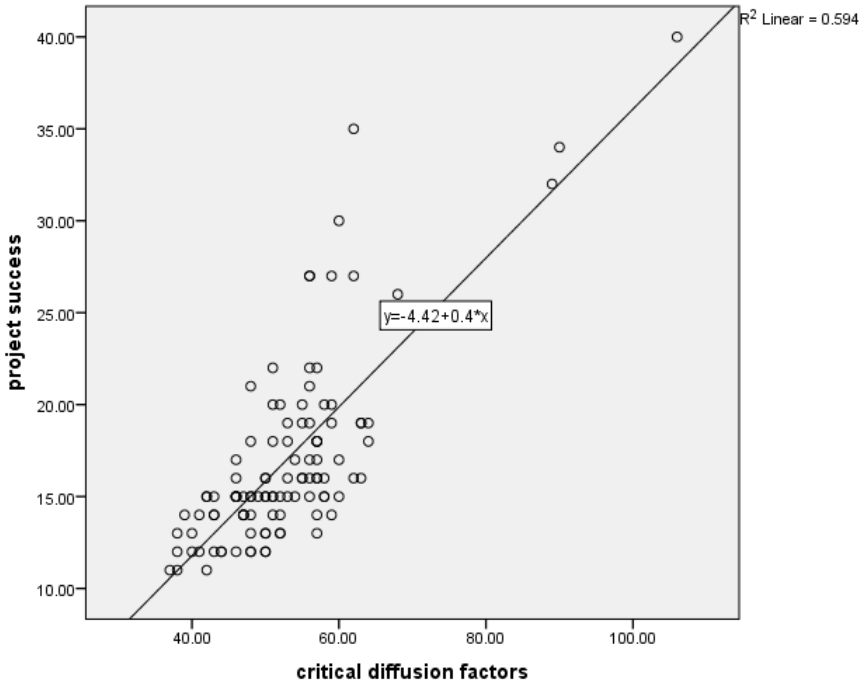

Figure 25: Combined diffusion factors and project success regression

According to the above, the identified diffusion factors are a positive predictor for project success with a very high statistically significant predictive capability which proves its goodness to fit.

Figure Number 25 above is a graphic representation of the regression line between the combined diffusion factors as a global IV and the project success as DV

The testing results of both the above stages has been summarised in Table 11 & 12 below:

Test no:	factor	R Square	Adj R Square	Std. Error of the Estimate	F	Sig
1	Relative advantage	.477	.472	3.816	95.706	.000b
2	compatibility	.347	.341	4.263	55.780	.000b
3	Trial-ability	.143	.134	4.885	17.464	.000b
4	Complexity	.368	.362	4.195	61.048	.000b
5	Observability	.594	.590	4.609	32.545	.000b
6	Global IV	.594	.590	3.361	153.621	.000b

Table 11: combined result of regression tests between IV clusters, IV global & Global DV.

Test no:	factor	Constant	B	Sig
1	Relative advantage	3.528	1.104	.000b
2	compatibility	3.295	0.870	.000b
3	Trial-ability	8. 237	0.698	.000b
4	Complexity	7.326	1.502	.000b
5	Observability	9.406	1.267	.008b
6	Global IV	-4.419	.405	.000b

Table 12: combined Beta value for all the linear regression tests

The results included in Table 11 & 12 above, along with the findings of the reliability and correlation tests have been discussed in detail in the next chapter.

5.7. Summary:

In this chapter, the data collected for the questionnaire survey has been loaded to the SPSS software, and accordingly analyzed to understand the frequency of distribution and data reliability. The components of the research were either the independent variable represented by factor clusters of the critical diffusion factors of 3D printing technology and the dependent variable represented by the project success, and both variable components have been tested for correlation and regression. The test output represented in this chapter will be challenged in the next chapter for deeper understanding and to conclude a firm opinion supporting the acceptance or rejection of the theoretical hypotheses and conceptual model identified in Chapter 3.

6. DISCUSSION

6.1. Introduction

Following the previous chapter where the output of the SPSS statistics had been represented, in this chapter, the tests' findings will be further discussed and understood. We will also see how the findings and results correlate with literature findings, and discuss the test result's impact on accepting or rejecting the previously concluded null hypothesis and conceptual model.

All the results reported in the SPSS tests have been critically challenged and deeply investigated to understand the motivation and the rationale that led to such results. For test results that were very different from anticipated or expected results, further literature review has been conducted to understand what the reasons for that could have been.

In this chapter, the null hypotheses and the conceptual model will be challenged against the test results, and the agreement or disagreement between the theoretical finding and the test results will be reported and explained.

6.2. Hypotheses testing

Although correlation analysis proves the association between the study variables, it is not enough to confirm the level of influence between the variable.

The linear regression test has, therefore, been conducted on each individual factor cluster of the independent variable against the global factor of the dependent variable in order to measure how much each cluster of 3D printing diffusion factors can influence the success of construction projects in the UAE. The test had also been conducted between the global factors of the independent variable and the global factors of the dependent variable to measure the influence of the combination of all identified factors together on the success of the construction projects in the UAE.

The test result has been displayed in Table 11 & 12 in the previous chapter, and will be analyzed one by one in line with the study hypotheses as follows:

Null hypothesis H_o: 3D printing technology diffusion factors do not influence the technology's successful application in the UAE's construction market.

The above null hypothesis H_o is assuming the absence of relationship and a significant influence between the acceptance/diffusion of the 3D printing technology (represented as IV in this study) and the success of the technology's application in the UAE's construction projects (represented as the DV). The correlation test in sections 5.4 and 6.3 confirmed the association between both variables, which support the rejection of the null hypothesis.

In order to confirm the rejection of the null hypothesis and to confirm the influence of the identified factors on the variation of project success ratio, the linear regression test has been conducted to predict the change in project success based on the change of diffusion factors identified in the five clusters of 3D printing diffusion factors combined. As per the test results, a significant regression equation was found as F (1, 105) = 153.621, p<.000 with an R^2 value of 0.594 which represents a statistically evident regression with high significance and shows that the regression model has a high degree of goodness of fit (as per table 11 above). Such a high degree of influence from the 3D critical diffusion factors on the project success is strong evidence to confirm the existence of a direct and statistically linear relationship between both variables. Consequently, **the Null Hypothesis, H_0, is rejected.**

Null Hypothesis $H_0$1a:"Success of the application of 3D technology in UAE's construction projects is not influenced by the level of value added by the application of 3D printing technology in the project compared to traditional method,

The above null Hypotheses $H_0$1a represents the absence of the influence of the relative advantage factors cluster of the 3D printing application on the success of construction projects in the UAE. The factors of this cluster have been extracted through literature review, and they have been grouped together in one scale of 8 items. The scale has been tested for reliability using the Cronbach alpha methodology, and the result of alpha was found to be .0796 which is deemed to be strongly accepted as per George and Mallery (2011). The items were also found to have good correlation between all items within the same scale and with other items within the same variable, and also had high significance correlation with other items within the dependent variable items as indicated in Table Number 10, and as explained in detail in sections 5.4 in the previous chapter.

In order to confirm the influence of the relative advantage factor cluster on the variation of the project success ratio, the linear regression test was conducted to predict the change in project success based on the change of diffusion factors identified in the relative advantage cluster. As per the test results, a significant regression equation was found as $F (1, 105) = 95.907$, $p<.000$ with an R^2 value of 0.447 which represented a statistically evident regression with a high significance, and the regression model was found to have a high degree of goodness of fit.

The line slope equation between the relative advantage and the project success can be written as $y = 3.53+1.1 * X$.

According to the above, the relative advantage is a positive predictor for the project success, with a very high statistically significant predictive capability which proves its goodness to fit. Since the influence of the relative advantage factors cluster is evident and has a significance of more than 95%, **the Null Hypothesis H_0 1a is rejected.** (Frick, 1996)

Null Hypothesis $H_0$1b:"Success of the application of 3D technology in the UAE's construction projects is not influenced by the degree of technology compatibility with the local industry standard.

The above null Hypotheses $H_0$1b is representing the absence of the influence of 3D printing technology's compatibility with local industry standards in the UAE on the success of the construction projects utilizing this technology in UAE. Technology compatibility has been represented by ten (10) items which have been grouped in one factor cluster and are used as an independent variable scale. The factors of this cluster has been extracted through literature review, and they have been grouped together in one scale of ten (10) items. The scale has been tested for reliability using the Cronbach alpha methodology, and the result of alpha was 0.709 which is deemed to be acceptable as per George and Mallery (2011),

All factors were also found to have good correlation with all items within the same scale, and with other items within the same variable. The factors also had a high correlation with other items within the dependent variable items, all of which had correlation factor values higher than 0.3 as per the data in table number 10 explained in detail in section 5.4 above.

Only one item did not have a correlation value higher than 0.3. This item showed a correlation value of 0.288, but had a strong significance value of p=.003. That item was, therefore, deemed the “suitability of selected method.“ The anomaly was, however, further investigated to figure out the reason behind this result. It was concluded that the reason for the erroneous value might be the fact that only one of the three available methods was being used locally.

Since the correlation value was close to the acceptance limit and it had a very high significance, it was decided to not delete the item from the study, nor from the conceptual framework.

In order to confirm the influence of the compatibility factor cluster on the variation of the project success ratio, the linear regression test was conducted to predict the change in project success based on the change of diffusion factors identified in the compatibility factors cluster. As per the test results, a significant regression equation was found as F (1, 105) = 55.780, $p<.000$ with an R^2 value of 0.347 which represents a statistically evident regression with high significance and it was proven that the regression model has a high degree of goodness of fit.

The regression line slope equation between the compatibility factor cluster and the project success can be written as y = 3.29+0.87 * X.

According to the above, the compatibility cluster of factors is a positive predictor of project success, with a very high statistically significant predictive capability which proves its goodness to fit. Additionally, since the influence of the compatibility factor cluster is evident with a significance more than 95%, **the Null Hypothesis H_0 1b is rejected.** (Frick, 1996)

Null Hypothesis $H_0$1c:“Success of the application of 3D printing technology in UAE’s construction project is not influenced by the ability to try & test the technology

The above null hypotheses H_a1c represents the absence of the influence of the ability to try and test the application of 3D printing technology on the success of construction projects in the UAE, The factors of this cluster have been extracted through the literature review, and they have been grouped together in one scale of eight (8) factors. The scale has been tested for reliability using the Cronbach alpha methodology and the result of alpha was 0.708 which id deemed to be accepted as per George and Mallery (2011). The items were also found to be with good correlation in between several items within the same scale, and with other items within the same variable. The items were also found to have a high significance correlation with other items within dependent variable items as per Table 10 above.

In order to confirm the influence of the trial-ability factor cluster on the variation of the project success ratio, the linear regression test has been conducted to predict the change in project success based on the change of diffusion factors identified in the trial-ability cluster. As per the test results, a significant regression equation was found as F (1, 105) = 17.464, p<.000 with an R^2 value of 0.143 which represents a statistically evident regression with a high significance and proves that the regression model has a high degree of goodness of fit.

The regression line slope equation between trail-ability and project success can be written as y = 8.24+0.698 * X.

According to the above, the trial-ability factor cluster is a positive predictor for project success, with a very high statically significant predictive capability which proves its goodness to fit. Additionally, since the influence of the trial-ability factor cluster is evident and has significance of more than 95%, **the Null Hypothesis H_0 1c is rejected.** (Frick, 1996)

.

Null Hypothesis $H_0$1d: Success of 3D application in UAE's construction project is not influenced by the level of complexity of 3D printing technology

The above hypotheses H_a1d represents the absence of influence of the complexity of the 3D printing technology application on the success of construction projects in the UAE. The factors of this cluster has been extracted through the literature review, and they have been grouped together in one scale of four (4) factors. The scale has been tested for reliability using the Cronbach alpha methodology and the result of alpha was 0.786 which is deemed to be accepted as per George and Mallery (2011). The items were also found to be with good correlation in between several items within the same scale, and with other items within the same variable, and also had high significance correlation with other items within the dependent variable items as per Table 10 above.

In order to confirm the influence of the complexity factor cluster on the variation of the project success ratio, the linear regression test has been conducted to predict the change in project success based on the change of diffusion factors identified in the complexity cluster. As per the test results, a significant regression equation was found as F (1, 105) = 61.048, $p<.000$ with an R^2 value of 0.368 which represents a statistically evident regression with high significance, and the regression model was found to have a high degree goodness of fit.

The regression line slope equation between the complexity factor cluster and project success can be written as y = 7.33+1.5 * X.

According to the above, the complexity factor cluster is a positive predictor for project success, with a very high statistically significant predictive capability which proves its goodness to fit. Since the influence of the complexity factor cluster is evident with significance of more than 95%, **the Null Hypothesis H_0 1d is rejected.** (Frick, 1996)

Null Hypothesis $H_0$1e:"Success of 3D application in UAE's construction projects is not influenced by the level of application observability.

The above Hypotheses H_a1e represents the absence of influence of the 3D printing technology application observability on the success of construction projects in the UAE. The factors of this cluster has been extracted through literature review, and have been grouped together in one scale of four (4) factors. The scale has been tested for reliability using the Cronbach alpha methodology and the result of alpha was 0.803 which is deemed to be accepted as per George and Mallery (2011). The items were also found to have good correlation with several items within the same scale, and with other items within the same variable. The items also had high significance correlation with other items within dependent variable items as per Table 10 above.

In order to confirm the influence of the observability factor cluster on the variation of the project success ratio, the linear regression test was conducted to predict the change in project success based on the change of diffusion factors identified in the observability cluster. As per test results, a significant regression equation was found as F (1, 105) = 32.545, $p<.000$ with an R^2 value of 0.237 which represents a statistically evident regression with a high significance and the regression model has a high degree of goodness of fit.

The regression line slope equation between the observability factor cluster and the project success can be written as y = 9.41+1.27 * X.

According to the above, the observability factor cluster is a positive predictor for project success, with a very high statistically significant predictive capability which proves its goodness to fit. Since the influence of the observability factors cluster is evident with significance of more than 95%, **the Null Hypothesis H_0 1e is rejected.** (Frick, 1996)

Null Hypothesis $H_0 2$: The diffusion of the 3D printing technology has no influence on the technology application success"

The above alternative Hypotheses $H_a 2$ is represents an absence of influence of all the identified factors combined on the success of the 3D printing projects in the UAE's construction market. The same testing method used to accept the previous alternative hypotheses was also used here, but in this case the global independent variable was tested against the global dependent variable.

In order to confirm the influence of the all the identified factors combined on the variation of the project success ratio, the linear regression test was conducted to predict the change in project success based on the change of diffusion factors identified in the five clusters of 3D printing diffusion factors combined. As per the test results, a significant regression equation was found as $F (1, 105) = 153.621$ $p<.000$ with an R^2 value of 0.594 which represents a statistically evident regression with high significance shows that the regression model has a high degree of goodness of fit.

The regression line slope equation between the observability and the project success can be written as $y = -4.42+0.4 * X$, which means that the project success increased by 0.4 units for each unit of diffusion factors increased.

According to the above, the identified diffusion factors are a positive predictor for project success, with a very high statistically significant predictive capability which proves their goodness to fit. Since the influence of the combined diffusion factor cluster is evident and significant, **the Hypothesis $H_0 2$ is rejected.** (Frick, 1996)

Null Hypothesis H03:" the integration of all critical diffusion factors of 3D printing technology have the same influence on the success of 3D printed application in UAE's construction projects compared to each factor's individual influence"

The above null hypotheses $H_0 3$ is concerned with the level of influence of the identified factors combined on the success of the 3D printed construction projects in comparison with the influence of each factor cluster individually which was tested during the rejection of the null Hypotheses $H_0 1$ (a-e) , and $H_0 2$ above.

Through analysing the data given in test number 6 of Table 11 & 12 above, it is evident that the value of the influence of the combined (global) factors is higher than the value of each individual factor, F value, & T value. Additionally, test number 6 shows the highest value of R2 which is 0.594. This means that 59% of the change in project success can be explained by the change of the critical diffusion factors, which is in itself a very high percentage and higher than any other individual factor cluster's influence. Additionally, the gap between both values of R^2 is very small ($R^2 = 0.594$, Adjusted $R^2 = 0.590$), which reflects the model's goodness of fit.

At the same time, the standard error of estimate for the global factor is the lowest value compared to individual factors, and the significance of correlation is the highest value at 100% of the results.

According the o above, the integration of all identified diffusion factors for 3D printing technology application will have the strongest influence on the project success and will lead to highest level of successful application of the 3D printed construction project in UAE. Hence, the **null Hypothesis $H_0 3$ is accepted.**

Furthermore, Tables 11, 12 above indicate that the relative advantage factor, the compatibility, and the complexity are relatively higher in regression value and significance compared to the other two factors, which were found to be matching with what was predicted by Tornatzky and Klein, (1982) as they have indicated that the relative advantage, the compatibility, and the complexity will have higher impact on innovation adoption compared to the trial-ability and observability.

According to above, the relative advantage, compatibility & complexity can be grouped together as primary factors, while trial-ability & observability can be grouped together as secondary factors.

In a trial to understand the impact of each of the primary factors and secondary factors individually, the liner regression test has been run between global dependent variable and each of the primary factors groups and secondary factors groups. The result for both tests in comparison with previous tests conducted between the global dependent variable and global independent variable are summarised in Table 7 below:

Factor	R	R Square	Adjusted R Square	Std. Error of the Estimate	F	Sig
Primary factors	. .760	.578	.574	3.42694	143.888	.000[b]
Secondary factors	.524[a]	.275	.268	4.49246	39.827	.000[b]
Global IV	.634[a]	.402	.387	2.78168	25.581	.000[b]

Table 13: combined result of regression tests of primary, secondary and global IV factors groups with global DV factor.

The results shown in table 13 above confirm the classification of the primary and secondary group, as when looking on the R^2 value and the F Value, it is evident that the primary factor clusters combined give a higher percentage of the project success change compared to the secondary factor clusters.

The result shown in Table 13 above also indicate that even though the secondary factors' group may have less influence individually, they still act positively when integrated with the primary factors group. Additionally, the significance factor is very high at almost 100% of the population. Therefore, optimum influence can be achieved through integrated implementation & occurrence for all the five factors simultaneously which again confirms the rejection of null Hypothesis $H_0 3$.

According to that finding, the conceptual model can be slightly revised to reflect the difference in impact and significance between the different factors.

6.3. Multicollinearity

In order to confirm the validity of the above investigated regression model in above tables 11, 12 &13, it was essential to conduct the variance inflation factor (VIF) analysis. This was especially important in this case since we have multiple independent variables and there is a high chance for the presented regression coefficient to be impacted by the multicollinearity relationship in-between the individual variable. In that case, the multicollinearity itself could be among the predictors. (Robinson, and Schumacker, 2009).

For this case, in order to confirm if there is multicollinearity in-between the variables, the variance inflation factor analysis test has been constructed while checking the regression in between the global dependant variable factor and the all the individual independent variables (five factors clusters). The same test was then repeated by replacing the global IV with each cluster of the IV and the result of the test was represented in Table 14 below

Coefficients[a]

Model		Collinearity Statistics Tolerance	VIF
1	reladvrev	.734	1.362
	compability	.436	2.294
	trialability	.552	1.811
	complixity	.685	1.461
	observability	.718	1.392

a. Dependent Variable: globalDV

Coefficients[a]

Model		Collinearity Statistics Tolerance	VIF
1	compability	.471	2.123
	trialability	.550	1.817
	complixity	.640	1.562
	observability	.661	1.512
	globalDV	.557	1.796

a. Dependent Variable: reladvrev

Coefficients[a]

Model		Collinearity Statistics Tolerance	VIF
1	reladvrev	.745	1.342
	trialability	.788	1.269
	complixity	.717	1.395
	observability	.760	1.316
	globalDV	.523	1.912

a. Dependent Variable: compability

Coefficients[a]

Model		Collinearity Statistics Tolerance	VIF
1	reladvrev	.680	1.470
	compability	.616	1.624
	complixity	.685	1.460
	observability	.754	1.326
	globalDV	.517	1.933

a. Dependent Variable: trialability

Coefficients[a]

Model		Collinearity Statistics Tolerance	VIF
1	reladvrev	.669	1.495
	compability	.474	2.111
	trialability	.579	1.727
	observability	.727	1.375
	globalDV	.543	1.843

a. Dependent Variable: complixity

Coefficients[a]

Model		Collinearity Statistics Tolerance	VIF
1	reladvrev	.669	1.495
	compability	.486	2.057
	trialability	.617	1.620
	complixity	.704	1.420
	globalDV	.551	1.815

a. Dependent Variable: observability

Table 14: variance inflation factor (VIF) analysis.

By inspecting the value of the VIF factor in table XX above, it was found that at all levels of the test, VIF value is always < 3.3 which is below the threshold for confirming the existence of multicollinearity (Kock and Lynn, 2012). Accordingly, it could be trusted that multicollinearity across study variables is weak, and its impact on the regression model can be ignored. This test further reconfirmed the finding stated above and supporting the acceptance of the study hypotheses and the conceptual model.

6.4. Finding Summary

According to test results, data analysis & discussions in previous chapters, the following results can be summarized as the study finding:

On macro level, the direct influence and association between each factor of the 3D printing critical diffusion factors on the success of the 3D printing technology application was found to be evident. The study shows how we can predict the change in the 3D printing project degree of success with the change of each factor of the identified diffusion factors.

On the micro level, each component of the five factors of 3D printing diffusion factor were found to be positively loading and impacting one or more of the project's success components, and in proper correlation with one or more other components within the same diffusion factor, or with other factors within the other five factors. Accordingly, all the identified thirty four components are accepted as influencing elements and none of them has been excluded from the study.

The factors of relative advantage, compatibility & complexity were found with a higher loading and stronger influence on the success of the technology application when compared with the trial-ability and observability. We can, therefore, identify the relative advantage, compatibility & complexity as primary factors, while the trial-ability and the observability are secondary factors.

Although the trial-ability and observability are identified as secondary factors, the integration & combined act of all factors together was found to be with a higher degree of influence compared to the influence of each factor individually, and higher than the value of the combined act of the primary factors only. Therefore, the study still suggests integration for all the diffusion factors together to obtain the optimum influence on the 3D printing project success.

6.5. Revised conceptual model

The proposed conceptual model in previous chapter 3.2 can be confirmed by the test results. It could, however, be slightly revised to be more informative about primary and secondary factor grouping, as the arrows representing the influence between variable has been represented with three different line weights, starting from direct and evident influence between variables which has been used to the represent the relationship between the secondary diffusion factors and the project success, to a stronger influence for the relationship between the primary diffusion factors group and the project success, and finally the strongest influence and the highest significance for the relationship between the integrated diffusion factor group with project success. The revised conceptual model is represented in Figure 26 below and its detailed version is in Figure 27 on the next page.

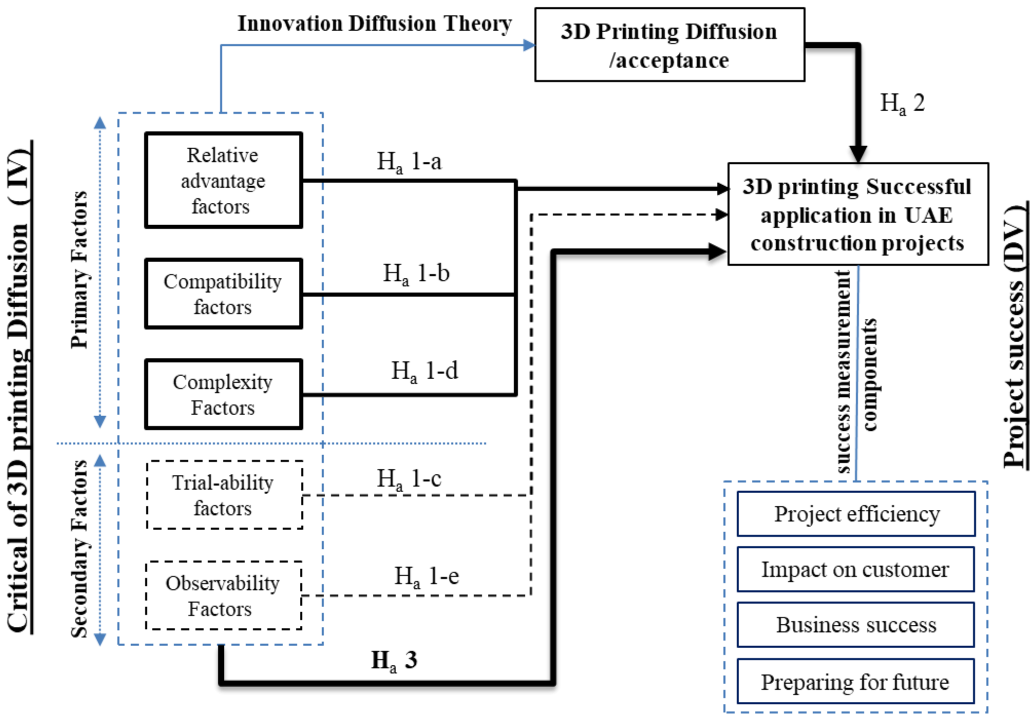

Figure 26: Revised theoretical conceptual Model

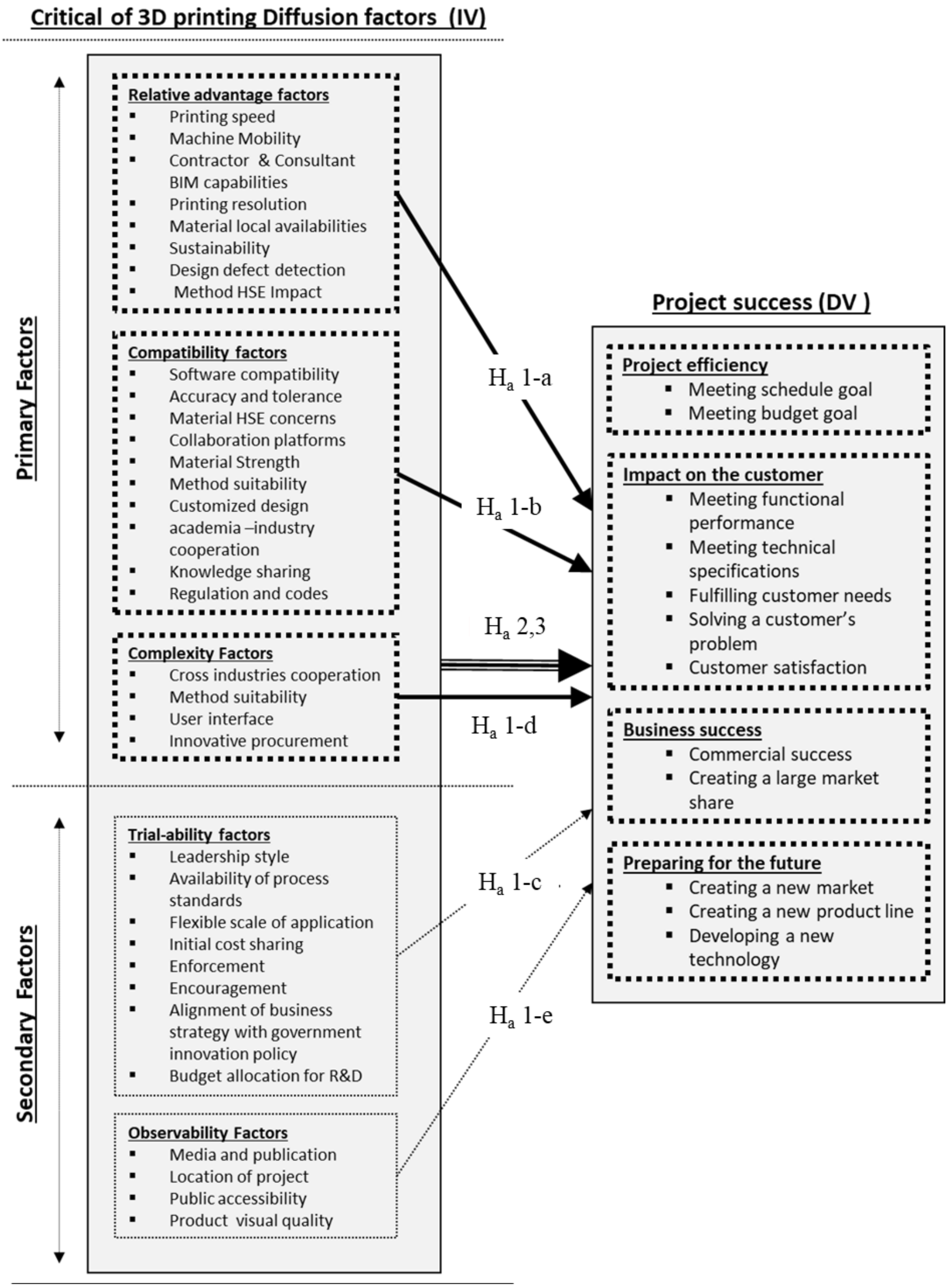

Figure 27: Revised theoretical conceptual Model (Detailed Version)

6.6. Summary

In this chapter, the output of the SPSS test results for the collected data from the survey questionnaire were deeply analyzed and discussed in light of the previously identified literature findings in Chapter 2, along with the concluded hypotheses and conceptual model in Chapter 3.

As a result, the collected data and its further analysis suggested the rejection of the null hypothesis & acceptance of the proposed alternative hypotheses as a positive influence was found to be evident between the identified factors clusters of the 3D printing diffusion factors on the success of the 3D printed projects - both on an individual level for each cluster separately, and on the global level when all the factors were acting together. Additionally, the level of influence of the factors combined was found to be higher than the value of each cluster individually which was also found to be supporting the literature finding.

During data analysis, three factor clusters were found to have a stronger influence compared to the other two factors which is why it was suggested to revise the conceptual model to differentiate between two groups of factors namely primary factors and secondary factors.

According the above summary, the objectives of this study have been satisfactorily achieved.

7. CONCLUSION

After all the study stages have been completed in previous chapters, this chapter will provide a brief summary on the study objectives, research problem, research methodology, and findings of the research. This chapter also will include a set of recommendations as a practical implication based on the study’s findings along with suggestions for future research opportunities based on this study’s limitations.

7.1. Study summary

This research topic is concerned with the application of 3D printing technology in the UAE's construction market which is a topic of interest by local market specialists. According to specialists, this technology may be responsible for the third industrial revolution and is the future the construction industry due to the great value it adds in terms of sustainability, construction speed, safer working conditions and many other attributes.

As the application of 3D printing technology is a part of the UAE government’s innovation policy, and the UAE government has recently announced its target of having at least twenty-five percent (25%) of the new buildings in Dubai to be built using 3D printing technology by the year 2030, the current technology diffusion and application is very far from expectation to achieve said target. And the market is still struggling to respond to such demand.

This research aimed to investigate the critical diffusion factors of the 3D printing technology that impact the success of projects in order to understand how to drive the technology application towards achieving the government’s target. The following points summarize how this study achieved its objectives:

The research focused on identifying the critical factors guided by the innovation diffusion theory developed by E.Rogers (Rogers, 2005). Through critical literature review, thirty four (34) factors were identified and classified under the five major attributes of the innovation diffusion theory as factor clusters. Those clusters are the relative advantage, the compatibility, the trail-ability, the complexity and the observability. All those thirty four 34 items were found to have an evident influence on the level of successful implementation and success of the 3D printed project.

The study suggests that the integration of all factors together will have a higher level of influence and will lead to higher level of application success.

The study findings highlighted the difference in the influence of the identified factor clusters, as data analysis found higher significance of the relative advantage, compatibility, and complexity clusters compared to the trial-ability and observability clusters. The study suggests calling the groups of factors included in the clusters of the relative advantage, compatibility & complexity as primary factors, while the factors included in the cluster of the trial-ability and observability were to be identified as secondary factors.

Both of the primary factors and secondary factors identified above are proven to be predictors to the application success, so regardless the level of influence, the study still suggested the wider application and the integration of all the identified factors in order to achieve the ultimate success of the technology.

Base on the research findings, a set of recommendations has been suggested to each of the market's key influencers (developers, consulates, constrictors, specialists, governments & research centers) as a guidance and highlight for the role which needs to be undertaken by each of them in order foresee a positive move towards achieving the government target which will be discussed in details in next section

This study is also filling a research gap, as this topic is considerably new, especially within the specific scope of its application, and the concluded results are based on both literature findings and quantitative research surveys that targeted market specialists who added value to its originality and reliability.

7.2. Practical implication

Based on the study finding and the revised conceptual model in section 6.8 above, the following set of recommendations could be suggested to the market stakeholders in order to move forward towards achieving the government target of having 25% of buildings in Dubai made out of 3D printing technology by the year of 2030:

7.2.1. Recommendation for developers:

The developers are deemed to be project initiators, and their role in technology acceptance is crucial for technology success. Based on the study's findings, certain actions are required to be undertaken by existing and future developers in order to support the technology success and wide application. These actions are summarized on the following set of recommendations to developers:

- Initiate/accept new forms of contracts for innovation & hi-tech projects like 3D printing based on the partnership environment.
- Align organization's business strategies with the government's innovation policy by initiating new projects based on the 3D printing technology-especially those projects which are accessible and visible by public
- Invest in media advertisement for the technology in both channels directed to public and the ones directed to specialists.

7.2.2. Recommendation for Consultants

Consultants' role in 3D printing successful application is crucial and essential, as they are the ones who outline the application scheme through valid and printable designs. They should be ready for the new era of construction and based on this study finding, the following actions are proposed to be undertaken by consultancy firms in order to contribute to the 3D printing application acceptance and success:

- Create a custom-made project design based on technology limitation and attributes that could maximize the benefit of the technology core value.
- Enhance in-house BIM capability

7.2.3. Recommendation for Contractors

Like consultants, contactors' role is also crucial for technology success. Contractors are the ones who will help the creative ideas of the innovation to be realized in the real world through successful implementation of the technology and ensuring the elimination of any other factors that may negatively impact the project's success. In order to do so, contractors should be ready and well prepared for successful implementation of 3D printing technology in construction. As the study's findings, the following actions are recommended to be undertaken by contractors to support the success of technology acceptance as successful application:

- Allocate a budget within company's financial plans for R&D works which can be utilized as initial cost sharing for pioneer projects
- Be familiar with all the different methods of 3D printing application in construction and choose the most suitable method to fit the project design.
- Enhance in-house BIM capability

7.2.4. Recommendation for technology specialists

Technology specialists as the ones who provide the tools for other involved parties. They are the ones who develop the technology from all its different aspects, and they are the ones who are supposed to listen to market needs and respond to them as fast as they can. Based on the study's findings, the following list of actions are proposed to be undertaken by technology specialists in order to ensure wide acceptance of the technology and high rate of success of its application:

- Concentrate research on parameters which give the technology advantage compared to the conventional construction method - with the primary focus on printing speed and printing quality.
- Develop a printing machine which is able to be easily transferred from a printing site to another, while paying more attention to on-site printing methodology.
- Coordinate with software developers to ensure the printing software is compatible with the common computers and operating systems, and ensure that it has a user-friendly software interface.
- Develop further research considering use of existing material in local market of UAE like local sand.

7.2.5. Recommendation for R&D Institutes

R&D institutes' role for technology development is pivotal for all involved parties as they create the platforms where all parties could have a proper interface and communicate. According to this study finding, the following actions are proposed to be undertaken by R&D institutes to support the 3D printing technology development and successful application:

- Work out with all different partners to develop widely recognized and accepted process standards.
- Take a lead role in coordination between different field experts to facilitate the cross-industry cooperation and knowledge sharing.
- Organize various events and conferences to give an opportunity for those experts to meet locally in the UAE.

7.2.6. Recommendation to Authorities:

Finally, while the previously mentioned parties are operating and interacting as a response to the government strategy and government call for technology application, the government's role is not any less importance. As per the study's findings, the following list of actions is suggested to be undertaken by the UAE government in order to facilitate a wider application of the 3D printing technology in the UAE's local construction market:

- Enforce technology application by emphasizing on targets, and take a lead on through enforcing technology application in governmental projects.
- Setup various reward schemes for innovative projects while assigning special credits for 3D application in the local construction market.
- Issue specific regulations and codes related to the application of 3D printing technology in construction while monitoring the codes & regulations, and updating them regularly to match the developments in the technology.

7.3. Future study

The study was limited by the availability of concerned literature on the specific study topic. Another limitation was the low number of real life examples and case studies on 3D printing application worldwide – and particularly in the UAE's local market. It is, therefore, recommended to revalidate the study's findings in the near future upon further development of the technology and wider application in local market.

The study identified two groups of factor clusters which namely the primary factor group and the secondary factor group. The relationship between these two groups and their individual impact on each other could be a subject of future study.

The study used the innovation diffusion theory to identify critical diffusion factors which impact the successful application of 3D printing technology. However, the innovation diffusion is not the only theory that is concerned with innovation perception and acceptance. Although innovation diffusion theory is the most common and famous, there is another theory which is the technology acceptance model (TAM) (Lee, Hsieh, and Hsu, 2011). TAM, too, could be used for future study and could help to identify some other factors not covered in this study.

The study figured out certain difficulties to predict the time frame for the development of the technology which was evident in error factors associated with the participants' response to the questions related to the impact of the future. It is suggested that the identified predictors (critical diffusion factors) be used along with the previous history of similar technology development to identify the required time frame for the 3D printing technology to mature and gain widespread acceptance and application in the UAE's local construction market. This could be a valid subject for subsequent studies.

7.4. Summary

The study was concerned with the identification of critical diffusion factors of 3D printing technology and how they influence the success of UAE's construction projects in response to the UAE government's target to increase the application of the technology in the field of construction. According to this study's findings, thirty four factors has been identified and verified to have an evident influence on the success of 3D construction projects in the UAE, and with this, the study's objective has been met.

To make the study more practical, a set of recommendations has also been suggested in the study. These suggestions should be undertaken by market influencers in order to facilitate the achievement of the UAE government's target to have twenty five percent (25%) of new buildings in Dubai built through 3D printing technology by the year 2030.

8. REFERENCES

[1] Abdalla Alfaki, I. and Ahmed, A. (2013). Technological readiness in the United Arab Emirates towards global competitiveness. *World Journal of Entrepreneurship, Management and Sustainable Development*, 9(1), pp.4-13.

[2] Abdallah, S., Khalil, A. and Divine, A., 2012. The impact of knowledge sharing on innovation capability in United Arab Emirates organizations. *Age*, *21*(25), p.23.

[3] Abdelsalam, H.M. and Gad, M.M., 2009. Cost of quality in Dubai: An analytical case study of residential construction projects. *International journal of project management*, *27*(5), pp.501-511.

[4] Abdullah saeed A, A. and Aimin, W. (2015). Market orientation and innovation: A review of literature. *International Journal of Innovation and Economic Development*, 1(1), pp.17-26.

[5] Abuelmaatti, A., 2014. Collaborative technologies for small and medium-sized architecture, engineering and construction enterprises: implementation survey. *Journal of Information Technology in Construction (ITcon)*, *19*(12), pp.210-224.

[6] Akintoye, A., Goulding, J. and Zawdie, G. eds., 2012. *Construction innovation and process improvement*. John Wiley & Sons.

[7] Al Hallami, M.O., Van Horne, C. and Huang, V.Z., 2013. Technological innovation in the United Arab Emirates: process and challenges. *Transnational Corporations Review*, *5*(2), pp.46-59.

[8] Al-Ansari, Y.D.Y., 2014. Innovation practices as a path to business growth performance: a study of small and medium sized firms in the emerging UAE market.

[9] Albaloushi, H. and Skitmore, M., 2008. Supply chain management in the UAE construction industry. *International Journal of Construction Management*, *8*(1), pp.53-71.

[10] Alinaitwe, H.M., Widén, K., Mwakali, J. and Hansson, B., 2007. Innovation barriers and enablers that affect productivity in Uganda building industry. *Journal of Construction in Developing Countries*, *12*(1), pp.59-75.

[11] Al-Khouri, A.M., 2012. eGovernment strategies the case of the United Arab Emirates (UAE). *European Journal of ePractice*, *17*, pp.126-150.

[12] Alsalami, E., 2012, May. Driving Organizational Innovation Through Transformational Leadership. In *International Conference on Excellence in Business, University of Sharjah, Sharjah, UAE*.

[13] Al-Tmeemy, S.M.H.M., Abdul-Rahman, H. and Harun, Z., 2011. Future criteria for success of building projects in Malaysia. *International Journal of Project Management*, *29*(3), pp.337-348.

[14] Aouad G, Ozorhon B, & Abbott C. (2010) Facilitating innovation in construction: Directions and implications for research and policy. *Construction Innovation: Information, Process, Management*. 10(4) 374-394

[15] Arayici, Y., Coates, P., Koskela, L., Kagioglou, M., Usher, C. and O'Reilly, K. (2011). BIM adoption and implementation for architectural practices. *Structural Survey*, 29(1), pp.7-25.

[16] Atkinson, R., 1999. Project management: cost, time and quality, two best guesses and a phenomenon, its time to accept other success criteria. *International journal of project management*, *17*(6), pp.337-342.

[17] Baccarini, D., 1999. The logical framework method for defining project success. *Project management journal*, *30,* pp.25-32.

[18] Balasubramanian, S. (2014). A structural analysis of green supply chain management enablers in the UAE construction sector. *International Journal of Logistics Systems and Management*, 19(2), p.131.

[19] Balasubramanian, S., 2012. A hierarchical framework of barriers to green supply chain management in the construction sector. *Journal of Sustainable Development*, *5*(10), p.15.

[20] Barnham, C., 2015. Quantitative and qualitative research: Perceptual foundations. *International Journal of Market Research*, *57*(6), pp.837-854.

[21] Baruch, Y. (1999). Response Rate in Academic Studies-A Comparative Analysis. *Human Relations*, 52(4), pp.421-438.

[22] Ben-Ner, A. and Siemsen, E., 2017. Decentralization and Localization of Production: The Organizational and Economic Consequences of Additive Manufacturing (3D Printing). *California Management Review*, 59(2), pp.5-23.

[23] Berman, B. (2013). 3D printing: the new industrial revolution. *IEEE Engineering Management Review*, 41(4), pp.72-80.

[24] Bhatia, U., 2015. 3D printing technology. *Int. J. Eng. Tech. Res*, *3*, pp.327-330.

[25] Blayse, A. and Manley, K. (2004). Key influences on construction innovation. *Construction Innovation*, 4(3), pp.143-154.

[26] Blind, K., 2012. The influence of regulations on innovation: A quantitative assessment for OECD countries. *Research Policy*, *41*(2), pp.391-400.

[27] Bos, F., Wolfs, R., Ahmed, Z. and Salet, T. (2016). Additive manufacturing of concrete in construction: potentials and challenges of 3D concrete printing. *Virtual and Physical Prototyping*, 11(3), pp.209-225.

[28] Bosqué, C. (2015). What are you printing? Ambivalent emancipation by 3D printing. *Rapid Prototyping Journal*, 21(5), pp.572-581.

[29] Buswell, R., Soar, R., Gibb, A. and Thorpe, A. (2007). Freeform Construction: Mega-scale Rapid Manufacturing for construction. *Automation in Construction*, 16(2), pp.224-231.

[30] Bygballe, L.E. and Ingemansson, M., 2014. The logic of innovation in construction. *Industrial Marketing Management*, *43*(3), pp.512-524.

[31] Calì, J., Calian, D., Amati, C., Kleinberger, R., Steed, A., Kautz, J. and Weyrich, T. (2012). 3D-printing of non-assembly, articulated models. *ACM Transactions on Graphics*, 31(6), p.1.

[32] Canessa, Enrique, Carlo Fonda, and Marco Zennaro. *Low-Cost 3D Printing For Science, Education & Sustainable Development*. ICTP—The Abdus Salam International Centre for Theoretical Physics, 2013. Print.

[33] Carvalho, M., Patah, L. and de Souza Bido, D. (2015). Project management and its effects on project success: Cross-country and cross-industry comparisons. *International Journal of Project Management*, 33(7), pp.1509-1522.

[34] Cavana, R.Y., Delahaye, B.L. and Sekaran, U., 2001. *Applied business research: Qualitative and quantitative methods*. John Wiley & Sons Australia.

[35] Chumnanklang, R., Panyathanmaporn, T., Sitthiseripratip, K. and Suwanprateeb, J., 2007. 3D printing of hydroxyapatite: effect of binder concentration in pre-coated particle on part strength. *Materials Science and Engineering: C*, *27*(4), pp.914-921.

[36] Conner, B., Manogharan, G., Martof, A., Rodomsky, L., Rodomsky, C., Jordan, D. and Limperos, J. (2014). Making sense of 3-D printing: Creating a map of additive manufacturing products and services. *Additive Manufacturing*, 1-4, pp.64-76.

[37] Cottle, S. (2011). Media and the Arab uprisings of 2011: Research notes. *Journalism: Theory, Practice & Criticism*, 12(5), pp.647-659.

[38] Coulon, M., Ernst, H., Lichtenthaler, U. and Vollmoeller, J. (2009). An overview of tools for managing the corporate innovation portfolio. *International Journal of Technology Intelligence and Planning*, 5(2), p.221.

[39] Creswell, J.W., 1994. Research design: Qualitative & quantitative approaches. Sage Publications, Inc.

[40] Design Middle East. (2018). *Architectural elements to spur 3D printing growth in UAE construction sector*. [online] Available at: http://www.designmena.com/thoughts/architectural-elements-to-spur-3d-printing-growth-in-uae-construction-sector [Accessed 6 Jun. 2018].

[41] Doyle, G., Garrett, B. and Currie, L. (2014). Integrating mobile devices into nursing curricula: Opportunities for implementation using Rogers' Diffusion of Innovation model. *Nurse Education Today*, 34(5), pp.775-782.

[42] D-shape.com. (2017). *d-shape printers | D-shape*. [online] Available at: https://d-shape.com/d-shape-printers/ [Accessed 2 Jun. 2017].

[43] Dulaimi M F, Y. Ling F Y, & Ofori G. (2002) Enhancing integration and innovation in construction. *Building Research and Information*. 30(4) 237-247

[44] Dumas, J., Hergel, J. and Lefebvre, S., 2014. Bridging the gap: automated steady scaffoldings for 3D printing. *ACM Transactions on Graphics (TOG), 33*(4), p.98

[45] Dvir, D., Raz, T. and Shenhar, A. (2003). An empirical analysis of the relationship between project planning and project success. *International Journal of Project Management*, 21(2), pp.89-95.

[46] Easterby-Smith, M., Thorpe, R. and Jackson, P.R., 2012. *Management research*. Sage.

[47] Easterby-Smith, M., Thorpe, R. and Lowe, A., 2002. Management research methods. London: Sage Publications Examinership-Friel Stafford, Available from www. liquidation. ie.

[48] Elmualim, A. and Gilder, J., 2014. BIM: innovation in design management, influence and challenges of implementation. *Architectural Engineering and design management*, *10*(3-4), pp.183-199.

[49] El-Saboni, M., Aouad, G. and Sabouni, A. (2009). Electronic communication systems effects on the success of construction projects in United Arab Emirates. *Advanced Engineering Informatics*, 23(1), pp.130-138.

[50] Emirates 24|7. (2017). *25% of Dubai's buildings will be 3D printed by 2030: Mohammed*. [online] Available at: http://www.emirates247.com/news/emirates/25-of-dubai-s-buildings-will-be-3d-printed-by-2030-mohammed-2016-04-27-1.628544 [Accessed 6 Apr. 2017].

[51] Faludi, J., Bayley, C., Bhogal, S. and Iribarne, M. (2015). Comparing environmental impacts of additive manufacturing vs traditional machining via life-cycle assessment. *Rapid Prototyping Journal*, 21(1), pp.14-33.

[52] Faridi, A. and El-Sayegh, S. (2006). Significant factors causing delay in the UAE construction industry. *Construction Management and Economics*, 24(11), pp.1167-1176.

[53] Farina, I., Fabbrocino, F., Carpentieri, G., Modano, M., Amendola, A., Goodall, R., Feo, L. and Fraternali, F. (2016). On the reinforcement of cement mortars through 3D printed polymeric and metallic fibers. *Composites Part B: Engineering*, 90, pp.76-85.

[54] Firestone, W.A., 1987. Meaning in method: The rhetoric of quantitative and qualitative research. *Educational researcher*, *16*(7), pp.16-21.

[55] Flynn, B.B., Sakakibara, S., Schroeder, R.G., Bates, K.A. and Flynn, E.J., 1990. Empirical research methods in operations management. *Journal of operations management*, *9*(2), pp.250-284.

[56] Forza, C., 2010. Surveys. In *Researching operations management* (pp. 98-175). Routledge.

[57] Foster, J. 2001. *Data Analysis Using Spss for Windows Versions 8 - 10*, Thousand Oaks, SAGE Publications, Limited.

[58] Foundation, D. (2017). *3D PRINTED OFFICE - DUBAI FUTURE FOUNDATION*. [online] Officeofthefuture.ae. Available at: http://officeofthefuture.ae/# [Accessed 3 Jun. 2017].

[59] Foy, D. and Shahbodaghlou, F., 2015. 3D Printing for General Contractors: an Analysis of Potential Benefits. In *ASC Proceedings of the 51st Annual Conference*.

[60] Freeman, M. and Beale, P., 1992, March. Measuring project success. Project Management Institute.

[61] Frick, R.W., 1996. The appropriate use of null hypothesis testing. *Psychological Methods*, *1*(4), p.379.

[62] Gao, W., Zhang, Y., Ramanujan, D., Ramani, K., Chen, Y., Williams, C.B., Wang, C.C., Shin, Y.C., Zhang, S. and Zavattieri, P.D., 2015. The status, challenges, and future of additive manufacturing in engineering. Computer-Aided Design, 69, pp.65-89.

[63] Garbarino, S. and Holland, J., 2009. Quantitative and qualitative methods in impact evaluation and measuring results.

[64] George, D. and Mallery, P. (2011). *SPSS for Windows step by step*. Boston, Mass. [u.a.]: Allyn & Bacon/Pearson.

[65] Glesne, C., 2011. Prestudy tasks: Doing what is good for you. Qualitative research and educational sciences: A reader about useful strategies and tools, pp.1-37.

[66] Gosselin, C., Duballet, R., Roux, P., Gaudillière, N., Dirrenberger, J. and Morel, P., 2016. Large-scale 3D printing of ultra-high performance concrete–a new processing route for architects and builders. *Materials & Design*, *100*, pp.102-109.

[67] Green, J. (2014). *3D Printing Can Empower Landscape Architects*. [online] THE DIRT. Available at: https://dirt.asla.org/2014/11/21/3d-printing-can-empower-landscape-architects/ [Accessed 6 Jun. 2018].

[68] Gruner, K. and Homburg, C. (2000). Does Customer Interaction Enhance New Product Success?. *Journal of Business Research*, 49(1), pp.1-14.

[69] Gu, F., 2005. Innovation, future earnings, and market efficiency. *Journal of Accounting, Auditing & Finance*, *20*(4), pp.385-418.

[70] Guba, E.G. and Lincoln, Y.S., 1994. Competing paradigms in qualitative research. *Handbook of qualitative research*, *2*(163-194), p.105.

[71] Heijmans N.V. (2018). *Test with 3D-Printed Concrete Formwork a Success*. [online] Available at: https://www.heijmans.nl/en/news/test-3d-printed-cement-formwork-success/ [Accessed 6 Jun. 2018].

[72] Heikal, M., Radwan, M.M. and Morsy, M.S., 2004. Influence of curing temperature on the Physico-mechanical, Characteristics of Calcium Aluminate Cement with air cooled Slag or water cooled Slag. *Ceramics-Silikáty*, *48*(4), pp.185-196

[73] Hong, K.K. and Kim, Y.G., 2002. The critical success factors for ERP implementation: an organizational fit perspective. *Information & management*, *40*(1), pp.25-40.

[74] Hwang, D. and Khoshnevis, B., 2004. Concrete wall fabrication by contour crafting. In 21st International Symposium on Automation and Robotics in Construction (ISARC 2004), Jeju, South Korea.

[75] Ismail, A., Mohamed, H.A.B., Sulaiman, A.Z., Mohamad, M.H. and Yusuf, M.H., 2011. An empirical study of the relationship between transformational leadership, empowerment and organizational commitment. *Business and Economics Research Journal*, *2*(1), p.89.

[76] Jiang, R., Kleer, R. and Piller, F. (2017). Predicting the future of additive manufacturing: A Delphi study on economic and societal implications of 3D printing for 2030. *Technological Forecasting and Social Change*, 117, pp.84-97.

[77] Kaner, I., Sacks, R., Kassian, W. and Quitt, T., 2008. Case studies of BIM adoption for precast concrete design by mid-sized structural engineering firms. *Journal of Information Technology in Construction (ITcon), 13*(21), pp.303-323.

[78] Khoo, Z., Teoh, J., Liu, Y., Chua, C., Yang, S., An, J., Leong, K. and Yeong, W. (2015). 3D printing of smart materials: A review on recent progresses in 4D printing. *Virtual and Physical Prototyping*, 10(3), pp.103-122.

[79] Khoshnevis, B. (2004). Automated construction by contour crafting—related robotics and information technologies. *Automation in Construction*, 13(1), pp.5-19.

[80] Khosravi, S. and Afshari, H., 2011, July. A success measurement model for construction projects. In *International Conference on Financial Management and Economics IPEDR*(Vol. 11, pp. 186-190). IACSIT Press Singapore.

[81] Kim, M., Cheng, J., Sohn, H. and Chang, C. (2015). A framework for dimensional and surface quality assessment of precast concrete elements using BIM and 3D laser scanning. *Automation in Construction*, 49, pp.225-238.

[82] Kock, N. and Lynn, G., 2012. Lateral collinearity and misleading results in variance-based SEM: An illustration and recommendations.

[83] Kothari, C.R., 2004. *Research methodology: Methods and techniques*. New Age International.

[84] Kothman, I. and Faber, N. (2016). How 3D printing technology changes the rules of the game. *Journal of Manufacturing Technology Management*, 27(7), pp.932-943.

[85] Kruth, J., Mercelis, P., Van Vaerenbergh, J., Froyen, L. and Rombouts, M. (2005). Binding mechanisms in selective laser sintering and selective laser melting. *Rapid Prototyping Journal*, 11(1), pp.26-36.

[86] Kumaraswamy, M. and Dulaimi, M. (2001). Empowering innovative improvements through creative construction procurement. *Engineering, Construction and Architectural Management*, 8(5/6), pp.325-334.

[87] Latteur, P., Goessens, S., BRETON, J.S., LEPLAT, J. and MUELLER, C., 2015. Drone-based additive manufacturing of architectural structures. *IASS 2015*.

[88] Le, T., Austin, S., Lim, S., Buswell, R., Gibb, A. and Thorpe, T. (2012). Mix design and fresh properties for high-performance printing concrete. *Materials and Structures*, 45(8), pp.1221-1232.

[89] Le, T., Austin, S., Lim, S., Buswell, R., Law, R., Gibb, A. and Thorpe, T. (2012). Hardened properties of high-performance printing concrete. *Cement and Concrete Research*, 42(3), pp.558-566.

[90] Lee, Y.H., Hsieh, Y.C. and Hsu, C.N., 2011. Adding innovation diffusion theory to the technology acceptance model: Supporting employees' intentions to use e-learning systems. *Journal of Educational Technology & Society*, *14*(4), p.124.

[91] Lim, S., Buswell, R., Le, T., Austin, S., Gibb, A. and Thorpe, T. (2012). Developments in construction-scale additive manufacturing processes. *Automation in Construction*, 21, pp.262-268.

[92] Lim, S., Buswell, R.A., Le, T.T., Wackrow, R., Austin, S.A., Gibb, A.G. and Thorpe, T., (2011). Development of a viable concrete printing process.

[93] Manyika, J., Chui, M., Bughin, J., Dobbs, R., Bisson, P. and Marrs, A., (2013). *Disruptive technologies: Advances that will transform life, business, and the global economy* (Vol. 180). San Francisco, CA: McKinsey Global Institute.

[94] Martin, S. and Scott, J. (2000). The nature of innovation market failure and the design of public support for private innovation. *Research Policy*, 29(4-5), pp.437-447.

[95] Melchels, F., Feijen, J. and Grijpma, D. (2010). A review on stereolithography and its applications in biomedical engineering. *Biomaterials*, 31(24), pp.6121-6130.

[96] Meskendahl, S. (2010). The influence of business strategy on project portfolio management and its success — A conceptual framework. *International Journal of Project Management*, 28(8), pp.807-817.

[97] Miniaoui, H. and Schilirò, D., 2016. Innovation and Entrepreneurship for the growth and diversification of the GCC Economies.

[98] Mir, F. and Pinnington, A. (2014). Exploring the value of project management: Linking Project Management Performance and Project Success. *International Journal of Project Management*, 32(2), pp.202-217.

[99] Moser, T., Mordinyi, R., Winkler, D. and Biffl, S., 2011, July. Engineering project management using the engineering cockpit: A collaboration platform for project managers and engineers. In *Industrial Informatics (INDIN), 2011 9th IEEE International Conference on* (pp. 579-584). IEEE.

[100] Mugenda, O.M., 1999. *Research methods: Quantitative and qualitative approaches*. African Centre for Technology Studies.

[101] Muhammad, M.R.R., 2015. The significance of Building Information Modelling to the Quantity Surveying practices in the UAE Construction Industry. In *6th International Conference on Structural Engineering and Construction Management, Kandy, Sri Lanka*.

[102] Müller, R. and Jugdev, K. (2012). Critical success factors in projects. *International Journal of Managing Projects in Business*, 5(4), pp.757-775.

[103] Murphy, M. (2014). Implementing innovation: a stakeholder competency-based approach for BIM. *Construction Innovation*, 14(4), pp.433-452.

[104] Nehemiah, M., Osden, J. and Pako, M. (2017). risk and opportunities connected to the adoption of internet banking in an emerging market. *Risk Governance and Control: Financial Markets & Institutions*, 7(2).

[105] Nelson Villaverde Chavez, F. (2015). Innovation in the Enterprise: Market Orientation as an Important Factor towards Product Innovation. *The International Journal of Management Science and Business Administration*, 1(11), pp.21-33.

[106] Nelson, R.R., 2005. Project retrospectives: Evaluating project success, failure, and everything in between. *MIS Quarterly Executive*, *4*(3), pp.361-372.

[107] Nerella, V.N., Krause, M., Näther, M. and Mechtcherine, V., 2016, June. Studying printability of fresh concrete for formwork free Concrete on-site 3D Printing technology (CONPrint3D). In *Rheologische Messungen an Baustoffen 2016: Tagungsband zum 25. Workshop und Kolloquium, 2. und 3. März an der OTH Regensburg*. tredition.

[108] Norusis, M.J., 1992. SPSS-PC Plus Base System User's Guide, Version 5.0. SPSS Incorporated.

[109] Olatunji, O.A., Sher, W. and Gu, N., 2010. Building information modeling and quantity surveying practice. *Emirates Journal for Engineering Research*, 15(1), pp.67-70.

[110] Organisation for Economic Co-operation and Development (2005), *Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data*, OECD Publishing, European Commission, Eurostat.

[111] Pegna, J. (1997). Exploratory investigation of solid freeform construction. *Automation in Construction*, 5(5), pp.427-437.

[112] Peres, R., Muller, E. and Mahajan, V., 2010. Innovation diffusion and new product growth models: A critical review and research directions. *International Journal of Research in Marketing*, *27*(2), pp.91-106.

[113] Perkins, I. and Skitmore, M. (2015). Three-dimensional printing in the construction industry: A review. *International Journal of Construction Management*, 15(1), pp.1-9.

[114] Perrot, A., Rangeard, D. and Pierre, A. (2015). Structural built-up of cement-based materials used for 3D-printing extrusion techniques. *Materials and Structures*, 49(4), pp.1213-1220.

[115] Polančič, G., Heričko, M. and Rozman, I. (2010). An empirical examination of application frameworks success based on technology acceptance model. *Journal of Systems and Software*, 83(4), pp.574-584.

[116] Polkinghorne, D.E., 2005. Language and meaning: Data collection in qualitative research. *Journal of counseling psychology*, *52*(2), p.137.

[117] Popescu, A.T., Stan, O. and Miclea, L., 2014, May. 3D printing bone models extracted from medical imaging data. In *Automation, Quality and Testing, Robotics, 2014 IEEE International Conference on* (pp. 1-5). IEEE.

[118] Porter, M.E. and Stern, S., 2001. Innovation: location matters. MIT Sloan management review, 42(4), p.28.

[119] Rayna, T. and Striukova, L. (2016). From rapid prototyping to home fabrication: How 3D printing is changing business model innovation. *Technological Forecasting and Social Change*, 102, pp.214-224.

[120] Ren, Z., Atout, M. and Jones, J., 2008, September. Root causes of construction project delays in Dubai. In *Procs 24th Annual ARCOM Conference* (pp. 1-3).

[121] Ritter, B. (2017). *The sky's the limit for 3D printing in construction – Middle East Construction News*. [online] Meconstructionnews.com. Available at: http://meconstructionnews.com/25340/the-skys-the-limit-for-3d-printing-in-construction [Accessed 6 Jun. 2018].

[122] Robinson, C. and Schumacker, R.E., 2009. Interaction effects: centering, variance inflation factor, and interpretation issues. *Multiple Linear Regression Viewpoints*, *35*(1), pp.6-11.

[123] Rogers, E. (2005). *Diffusion of innovations*. 1st ed. New York: Free Press.

[124] Sabie, K.K., Pitts, A. and Nicholls, R., 2014. Sustainability Assessment Methods for the Gulf Region.

[125] Salet, T.A.M. and Wolfs, R.J.M., 2016. Potentials And Challenges In 3D Concrete Printing.

[126] Schilirò, D. (2015). Innovation in Small and Medium Enterprises in the United Arab Emirates. *International Journal of Social Science Studies*, 3(5).

[127] Serrador, P. and Turner, R., 2015. The relationship between project success and project efficiency. *Project Management Journal*, *46*(1), pp.30-39.

[128] Shenhar, A.J., Dvir, D., Levy, O. and Maltz, A.C., 2001. Project success: a multidimensional strategic concept. *Long range planning*, *34*(6), pp.699-725.

[129] Shibani, A., Saidani, M. and Alhajeri, M., 2013. Health and safety influence on the construction project performance in United Arab Emirates (UAE). *Journal of Civil Engineering and Construction Technology*, *4*(2), pp.32-44.

[130] Shneiderman, B., 2000. Creating creativity: user interfaces for supporting innovation. *ACM Transactions on Computer-Human Interaction (TOCHI)*, *7*(1), pp.114-138.

[131] Shrnhur, A.J., Levy, O. and Dvir, D., 1997. Mapping the dimensions of project success. *Project management journal*, *28*(2), pp.5-13.

[132] Sills, S.J. and Song, C., 2002. Innovations in survey research: An application of web-based surveys. *Social science computer review*, *20*(1), pp.22-30.

[133] Singh, V., Gu, N. and Wang, X. (2011). A theoretical framework of a BIM-based multi-disciplinary collaboration platform. *Automation in Construction*, 20(2), pp.134-144.

[134] Singh, V., Gu, N. and Wang, X., 2011. A theoretical framework of a BIM-based multi-disciplinary collaboration platform. *Automation in construction*, *20*(2), pp.134-144.

[135] Sivadas, E. and Dwyer, F.R., 2000. An examination of organizational factors influencing new product success in internal and alliance-based processes. *Journal of marketing*, *64*(1), pp.31-49.

[136] Slaughter E S. (1998) Models of Construction Innovation. *Journal of Construction Engineering and Management* 124(3) 226-231

[137] Small, E. and Mazrooei, M. (2016). Evaluation of Construction-specific Provisions of Sustainable Design Codes and Standards in the United Arab Emirates. *Procedia Engineering*, 145, pp.1021-1028.

[138] Smith, J. and Noble, H., 2014. Bias in research. *Evidence-based nursing*, pp.ebnurs-2014.

[139] Sonnenwald, D.H., Maglaughlin, K.L. and Whitton, M.C., 2001. Using innovation diffusion theory to guide collaboration technology evaluation: work in progress. In *Enabling Technologies: Infrastructure for Collaborative Enterprises, 2001. WET ICE 2001. Proceedings. Tenth IEEE International Workshops on* (pp. 114-119). IEEE.

[140] Stewart-Weeks, M. and Kastelle, T. (2015). Innovation in the Public Sector. *Australian Journal of Public Administration*, 74(1), pp.63-72.

[141] Straub, J. (2015). Initial Work on the Characterization of Additive Manufacturing (3D Printing) Using Software Image Analysis. *Machines*, 3(2), pp.55-71.

[142] Tornatzky, L. and Klein, K. (1982). Innovation characteristics and innovation adoption-implementation: A meta-analysis of findings. *IEEE Transactions on Engineering Management*, EM-29(1), pp.28-45.

[143] Tumbleston, J., Shirvanyants, D., Ermoshkin, N., Janusziewicz, R., Johnson, A., Kelly, D., Chen, K., Pinschmidt, R., Rolland, J., Ermoshkin, A., Samulski, E. and DeSimone, J. (2015). Continuous liquid interface production of 3D objects. *Science*, 347(6228), pp.1349-1352.

[144] Uaecabinet.ae. (2017). *News*. [online] Available at: https://uaecabinet.ae/en/details/news/mohammed-bin-rashid-uae-is-an-incubator-of-innovation-and-future-technology [Accessed 3 Jun. 2017].

[145] Venkatesh, V., Brown, S.A. and Bala, H., 2013. Bridging the qualitative-quantitative divide: Guidelines for conducting mixed methods research in information systems. *MIS quarterly*, *37*(1).

[146] Wang, S., Wang, F., Han, Y. and Meng, F., 2014. Acquire 3D Print Three-dimensional Data Field and Filling Optimization 2D Contour Lines.

[147] Wong, K.V. and Hernandez, A., 2012. A review of additive manufacturing. *ISRN Mechanical Engineering*, *2012*.

[148] Wright, K.B., 2005. Researching Internet-based populations: Advantages and disadvantages of online survey research, online questionnaire authoring software packages, and web survey services. *Journal of computer-mediated communication*, *10*(3), p.JCMC1034.

[149] Wu, P., Wang, J. and Wang, X. (2016). A critical review of the use of 3-D printing in the construction industry. *Automation in Construction*, 68, pp.21-31.

[150] Xue, X., Zhang, R., Yang, R. and Dai, J. (2014). Innovation in Construction: A Critical Review and Future Research. *International Journal of Innovation Science*, 6(2), pp.111-126.

[151] Yates, S., 2003. Doing social science research. Sage.

9. APPENDICES

Appendix 1 – Survey Questionnaire

British University in Dubai

Student survey on preparation of master program Dissertation

Dissertation Topic: Critical factors influencing the Success of 3D printing technology application in UAE construction Projects

1. INTRODUCTION

Although the concept of three-dimensional (3D) printing is always promoted as a key form of innovation in several fields and industries, but in fact the researches around that concept has been discussed since 1980's, for the last 4 decades the technology has witnessed a severe development bypassing day by day the limitation of application in terms of improvement of machines, printing inks and printing methodologies. As happen in many other industries, the construction specialists interest in utilizing the 3D printing technology in printing buildings either fully or partially is increasing day by day, aiming to convert the Construction site into large scale printing field.

There are different methods of printing, and there are different applications of the printing technology in construction industry, the projects can be directly printed on-site, or it can be printed offsite and transported to the final location either in full size or in a separate parts depending on the project size.

Key advantages of this technology are to reduce involvement of human factor in construction process, as well as minimize or eliminate construction waste. The technology can open up new possibilities for designers as it reduce their limitation on creative designs. With 3D printing, the fact of modularization and size standardization are no more critical for cost efficiency if compared with precast or other conventional methods.

The interest in 3D printing application in construction field particularly in United Arab Emirates (UAE) is greater than any other spot in the world, not only because UAE Interest to be world leader in Innovation in General. But also due to the announcement made of His Highness Sheikh Mohammed Bin Rashid Al Maktoum, Vice President and Prime Minister of the United Arab Emirates and Ruler of Dubai, when he declared Government target to reach 25% of Dubai new construction Building out of 3D printing by the year of 2030.

But since construction industry is well known by its conservation against innovation, applying new ideas or new concepts of construction will be faced with a noticeable reluctance from market towards adoption of such change. Which is a great barrier towards wide application of the new concepts, adding to that, although the technology of 3D printing is almost 40 years old so far, the technology application in construction is yet premature, and still far away from realistic and practical application on large scale with the required economic efficiency. Those barriers are standing against wide spread of technology and further obstructing the emirate target form being achieved.

One of the famous examples of the technology application is the Office of the future project (OOTF), which is the first application of the technology on a full scale functioning building.

The project is a single story building around 200 square meters, the structure of the building was printed offsite in pieces, and shifted to site for assembly, the project is located in a very prime location just next to the emirates tower location on the famous sheikh Zaid Road, and the Financial center round about.

Time wise, the project took 7 months of overall duration, from the first day of project launching till the official opening, which includes the design, approvals, offsite printing, transportation, construction and commissioning.

But looking the construction duration independently, for the part which is related to the 3D printing application which is the structure, it took 17 days to print the entire structure offsite and 3 days for onsite assembly, so if we excluded the transportation gap, the entire structure of the project has been completed in 20 days.

The major challenges the project had was the absence of dedicated regulation related to 3D printing application in local authority system, which has been resolved by applying the codes of precast for that project, but that was negatively affecting the detailing and costing of the project, but was an important lesson learned, and after that project the local authority realized such problem and started to work on preparing and issuing a specific code for 3D printing construction.

The printed material for the structure is a cement based ink, the designer had introduced a cladding layer on top of it for architecture purpose. You may refer to above information and the below photos to enrich your knowledge about the project.

This research is concerned with the identification of the Key success factors which push towards more successful application of 3D printing technology in construction project focusing on the context of UAE in particular. You are kindly requested to answer the below question based on your personal experience and knowledge. Please feel free to bypass any question which you may not have a clear answer or you lack to technical information related to the question.

2. SURVEY QUESTIONNAIRE

Personal information:

Age group:	20-29	30-39	40-49	50-59	60 and above
Occupation:	Junior	senior	mid management	senior management	others
Gender:	Male		female		
Organization Commitment:	Contractor	Consultant	Client /Developer	Specialist supplier	others
Education level	High School	Bachelor's degree	Master's degree	PHD	others

Relative advantage factors:

1- 3d printing technology can help to deliver projects faster than conventional methods.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

2- The possibility of moving the printing machine to site can resolve several logistic problems compared to conventional methods

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

3- A contractor and consultant BIM capability is essential to successful implementation of 3D printing technology in Construction.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

4- Quality 3D printing products as of today is serious constrain for application when comparing to quality of conventional methods output.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

5- Unavailability of 3D printing materials in local market of UAE is a great barrier for the technology implementation if compared with conventional methods

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

6- 3D printing technology can deliver more sustainable & environmental buildings compared to conventional construction methods.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

7- The possibility of detecting design flaws and errors before printing will give a great advantage to the 3D printing technology compared to conventional construction methods.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

8- 3D printing technology offers a good advantage to the HSE aspects compared to conventional methods.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

Compatibility factors:

9- Compatibility of printing software with common design & BIM software is important factor, which could be a strong barrier against wide implementation of technology application.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

10- 3D printing technology must be able to deliver products within the accepted tolerance and accuracy of International standards and code of the conventional construction methods in order to be widely accepted.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

11- Raised concerns about the use of fiber glass and other chemicals within the 3D printing materials can be a major barrier against technology implementation.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

12- Common Collaboration platforms (cloud sharing and exchange of information), can play essential role in resolving compatibility issues between different involved parties.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

13- 3D printing material strength is essential to meet design criteria and local codes in UAE.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

14- With the fact that there are several methods for 3D printing application in construction industry, selecting the most suitable method for each project is essential for successful implementation.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

15- Application of 3D printing should be considered in very early stage of design, accordingly designer should be produced a customized designs special for 3D printing implementation.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

16- A high level of cooperation between academic research institutes and industry sector is essential for technology development towards its objectives.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

17- High level of knowledge sharing and transparency is required to reinforce the cooperation and success of the 3D application, while constrains related to copy rights and intellectual property will stand as barrier against that.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

18- Local codes and regulation in UAE require optimization to allow the adoption of 3D printing technology in Construction in UAE local market.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

Trial-ability factors:

19- Organization leadership style which support trying and testing of new technology is contributing positively in spreading the technology wider.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

20- unavailability of clear and recognized standards of 3D printing design and execution is negatively impact the wide adoption of 3D printing technology in local market

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

21- The possibility of trying the technology on a small scale can encourage more stakeholders to explore more about the technology and can open further opportunity for larger application.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

22- Cost sharing at initial trial stage is a positive motivation for all concerned parties to try the technology and work hard on overcome any problems may raise during the trial session.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

23- UAE Authority enforcement of technology adoption in construction sector by certain percentage is a great push for local market to take a lead in the technology application worldwide.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

24- Various reward systems for pioneer projects and researches on 3D printing projects is a positive motivation for various decision makers to invest time and money on technology development and application

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

25- When construction organizations business strategies are not aligned with UAE government policy of innovation adoption, progress of 3D printing application in construction will be slow down.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

26- Construction Organization who don't allocate budget for R&D within their financial models will be struggling to adopt new technology such as the 3D printing in technology.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

Complexity factors

27- The cooperation between various experts involved in 3D printing technology application in construction (ie: electronics, materials, construction, Design...etc.) will help to overcome complexity issues related to development and application.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

28- It is essential to choose the simplest method for printing which suite the project objectives as choosing more complicated method without a real need can lead to rebel the interest of some stake holders.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

29- My organization will be more interested in trying the 3D printing technology in construction if the process was simple and the interface of printing software is user Friendly.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

30- 3D printing technology requires a special form of construction contracts and innovative form of procurement.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

Observability

31- Projects built out the 3D printing technology in UAE are well advertised in media and public advertisement.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

32- My organization will be more interested in the 3D printing projects if they are located in prime location where it can be well observed by public

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

33- My organization will be more interested in the 3D printing projects if it has been deployed in projects which is accessible by public (public facilities) compared to other projects which will be private facilities

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

34- The final product visual quality of 3D printed acts positively to attract attention to the project.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

Project success measures:

35- The 3D printing technology can help projects to meet its schedule targets.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

36- The 3D printing technology can help projects to meet its cost targets.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

37- 3D printed projects fit its intended purpose.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

38- 3D printed projects are guaranteed to achieve its targeted technical specification.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

39- 3D printed projects are satisfying their customers' needs.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

40- Clients and end users of 3D printed projects are satisfied about project.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

41- Projects made out of 3D printing is a successful business case for involved organization

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

42- Organizations who can utilize 3D printing technology will have a larger market share in UAE construction market.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

43- There is promising future for 3D printing technology application in UAE construction market future.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

44- 3D printing projects is opening UAE construction market to new forms of products and suppliers.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

45- Implementation of 3D printing technology in real projects can help to push the technology development further ahead.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

Any other information to add :

End of Survey – Thank you for participation