THREE-DIMENSIONAL PRINTING TECHNOLOGY ADOPTION OF CONSTRUCTION INDUSTRY IN KUNMING, THE PEOPLE'S REPUBLIC OF CHINA

By

Mr. Zhikang ZHOU

A Thesis Submitted in Partial Fulfillment of the Requirements
for Master of Engineering ENGINEERING MANAGEMENT
Department of INDUSTRIAL ENGINEERING AND MANAGEMENT
Silpakorn University
Academic Year 2023

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โดย
Mr.Zhikang ZHOU

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรวิศวกรรมศาสตรมหาบัณฑิต
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By	Mr. Zhikang ZHOU
Field of Study	ENGINEERING MANAGEMENT
Advisor	Noppakun Sangkhiew, Ph.D.

Faculty of Engineering and Industrial Technology, Silpakorn University in Partial Fulfillment of the Requirements for the Master of Engineering

.... Dean of Faculty of Engineering and Industrial Technology
(Assistant Professor Arunsri Leejeerajumnean, Ph.D.)

Approved by

.... Chair person
(Associate Professor Choosak Pornsing, Ph.D.)

.... Advisor
(Noppakun Sangkhiew, Ph.D.)

.... External Examiner
(Thanongsak Thepsonthi, Ph.D.)

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This reseach studies applying three-dimensional printing technology in the construction industry in Kunming. A questionnaire consisted of three sections with 53 questions: demographic, current situation, and technology adoption sections. Importantly, section 3 was invented with 30 questions that fall into nine groups following the technology adoption area: relative advantages, complexity, trialability, compatibility, absorptive capacity, external pressure, uncertainty, supply-sided benefits, and demand-side benefits.

The questionnaire was tested by item-objective congruence index by three experts. Two hundred sixty-eight questionnaires were collected and analyzed. The results show that there were few construction projects implementing 3D printing technology. The technology is acceptable in terms of investment, and construction performance improvement. On the other hand, the challenges of technology adoption are the lack of skilled workers who can work with 3D printers, and the initial investment is high.

Futhermore, the first three key factors of three-dimensional printing technology adoption are supply-sided benefits, external pressure, and relative advantages, with scores of 4.13, 4.05, and 3.98, respectively. It means adopting three-dimensional printing technology in Kunming's construction industry; they need to explicitly present the technology's benefits to the demand side. Furthermore, they need to rigorously improve their knowledge and skilled workers for three-dimensional printing technology. Finally, other advantages, such as construction time, material usage, construction cost, and manpower, must be reduced significantly.

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Zhikang ZHOU

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CHAPTER 1
INTRODUCTION

1.1 Motivation

The construction industry is the top significant industry in the world. It possesses annual revenue of 10 trillion USD, about 6% of the worldwide GDP (El-Sayegh et al., 2020). Engineering and construction fields are essential to the functioning of the global economy. Over the course of the last couple of decades, the building and construction sector has witnessed a number of significant advancements. Construction organizations are constantly on the lookout for new ways to boost efficiency while simultaneously cutting costs (Maskuriy et al., 2019). The manufacturing sector has seen an increase in the amount of output per hour of labor. Studies, on the other hand, have indicated that worker productivity in the construction sector has been on a downward trend throughout the years (Bokc, 2015). One of the reasons for this drop is that new technology has not been fully implemented.

The most difficult and time-consuming aspects of manufacturing are slated to be digitized as part of the fourth wave of the industrial revolution, known as Industry 4.0. This development was primarily applied to the manufacturing business, and its applications in the construction industry, which are still in their infancy, were a secondary focus. One of the most recent kinds of technology brought into the building and construction industry is additive manufacturing (AM), more popularly known as three-dimensional printing (3D printing) technology. This technology is one of the primary drives toward digitalizing the building and construction sector. Both the automotive and industrial sectors have benefitted from the wide range of technologies introduced by Industry 4.0, which has led to an improvement in the overall performance of the industries and the quality of the goods themselves (Oesterreich & Teuteberg, 2016). Industry 4.0 was implemented at a slower rate in the construction sector compared to the manufacturing industry, despite its numerous benefits.

Nevertheless, using 3D printing into building projects introduces extra hazards. A risk is an unpredictable occurrence that could have an effect, either good or negative, on at least one of the goals of the project (Tay et al., 2017). Construction projects are inherently dangerous since they include the use of a variety of materials and several stakeholders, each of which has their own unique goals. In addition, much of the work in construction is done outside, where it is exposed to many natural hazards. There is a high risk that the initiative will not be successful. When it comes to building projects, cost and time overruns are the result of insufficient risk management. Internal and external risks are the two categories that are used to classify dangers in building projects (El-Sayegh, 2008). The project level, also known as the micro level, is where internal risks are managed, whereas the macro level is where external risks are managed. Risks that are posed by the outside world include those that are political, environmental, and economical. Internal risks may be broken down into categories such as technical, design, material, contractual, and liability concerns.

In addition, Liu et al. (2023) reported slow progress in adopting 3D printing technologies in the construction industry because many different factors affect 3D printing adoption (Muylle, 2019). For example, the employee's age, knowledge, and skill influence new technology adoption. Other significant factors are the cost of 3D printing technology, such as machines, robots, materials, software, maintenance, and training (Pimpley, 2019). The significant attributes are the local competition, technology supply chain, and technology providers.

Thus, in this study, the researcher would like to investigate the influence factors of 3D printing technology adoption in the local area of Kunming, the People's Republic of China. The present implementation of the technology is also enjoyable. The critical research method is survey methodology for receiving primary data in the study area.

1.2 Research Question

There is one primary question in this study "What are factors influencing the adoption of 3D printing in construction and to what is the situation of 3D printing technology already adopted in Kunming, the People Republic of China?"

1.3 Research Objectives

1. To investigate potentials and challengers of adopting concrete 3D printing technology in construction industry in Kunming, the People's Republic of China.

2. To report the current situation of 3D printing technology implementation in construction industry in Kunming, the People's Republic of China.

1.4 Research Contributions

1. This study will report the current situation of new technology adoption of construction industry in Kunming which can be imply to other advanced technologies.

2. The findings can lead the management to launch new strategies in new technologies implementation in construction industry.

3. Fulfilling the knowledge gap among different countries in new technology adoption.

1.5 Scope and Limitations

1. The area of study is Kunming, a capital city of Yunnan province, People's Republic of China.

2. The duration of data collection is between November 2023 and December 2023.

3. This study is a survey research using statistical tools for data analysis. There is no guarantee for other study areas.

1.6 Abbrviation

2D Two-dimensional

3D Three-dimensional

3DCP 3D Concrete Printing

3DP 3D Power

3D Printing Three-dimensional Printing

AEC Architecture, Engineering, and Construction

AM Additive Manufacturing

AMIE Additive Manufacturing and Integrated Energy

AR Augmented Reality

ASTM American Society for Testing and Materials

BAAM Big Aream Additive Manufacturing

BIM Building Information Modelling

BJ Binder Jetting

CAD Computer-aided Design

CC Contour Crafting

CEO Chief Executive Officer

CVR Content Validity Ratio

DCP Digital Construction Platform

DED Direct Energy Deposition

DOI Diffusion of Innovation

FDM Fused Deposition Modelling

Industry 4.0 (The) Fourth Industrial Revolution

LEED Leadership in Energy and Engineering Design

LOM Laminated Object Manufacturing

ME Material Extrusion

MEP Mechanical, Electrical, and Plumbling

MR	Mixed Reality
MJ	Material Jetting
PLA	Polylactic Acid
R&D	Research and Development
RP	Rapid Prototype
SL	Sheet Lamination
SLA	Stereolithography Apparatus
TAM	Technoloy Acceptance Model
TOE	Technology-Organizational-Environment
UAM	Ultra-sonic Additive Manufacturing
UV	Ultra Violet
VR	Virtual Reality
VP	Vat Photopolymerization

CHAPTER 2

LITERATURE REVIEW

2.1 Three-dimensional Printing Technology

The technique that is utilized in 3D printing is called fused deposition modeling, or FDM for short. With this method, the printer extrudes a layer of building material out of the nozzle in a layer and then stacks those layers in accordance with the programmed 3D model, growing the walls of the building. There are a variety of applications available now that may be used to generate a 3D model (Elasad & Amirov, 2020). There is no cost associated with accessing these services.

There are a few different definitions of what three-dimensional printing is, but ultimately they all refer to the same thing. According to Vardhan et al. (2014), the process of 3D printing begins with a digital model and generates solid items in three dimensions through an automated additive manufacturing procedure. The concept of additive manufacturing is most commonly understood to refer to three-dimensional printing when discussing published works. The first 3D printer was created in 1984, and in recent years, this technology has been seeing rapid expansion, with a greatly expanded utilization across a wide variety of industry domains (Avrutis et al., 2019). The year 1984 saw the development of the first 3D printer. Applications in aerospace, the food industry, medical and healthcare applications, applications in the automotive industry, design, jewelry, the fashion industry, toys, etc. (Masera et al., 2017). This automated production process with layer-by-layer control has a huge potential in many different industries. According to Masera et al. (2017), despite the fact that three-dimensional printing is already mature in a few sub-sectors of the manufacturing business, the construction industry still has some ground to make up, and there is room for improvement in terms of the quality of practical examples in this industry.

According to the report of Baigarina et al. (2023), the steps of the 3D printing workflow depicted in Fig. 2.1 are the most important. AM is capable of producing forms that may be delineated in 3D printing; nevertheless, in order to finish the project, a CAD file is required. It takes a significant amount of time to create digital models for 3D printing, even though 2-D representations are still generally accepted as the norm in the construction industry for the delivery of completed projects. The conventional methods for converting two-dimensional drawings into three-dimensional models have several drawbacks, including low quality and slowness. Structure information modeling, often known as BIM, is a relatively recent method that uses digital representation to depict a structure's structural and functional components. BIM procedures give the capacity to organize project data, including material characteristics, construction typology, and building geometry, which may be used to make informed judgments (Holt et al., 2019). This ability can be used to make knowledgeable decisions about the project. In contrast to more conventional 3D modeling software, Building Information Modeling (BIM) incorporates not just information on geometry but also data on fabrication, spatial connections, and the performance of materials. Building Information Modeling (BIM) has been shown to be an effective technology for aiding 3D printing in the building industry.

In addition, BIM specifies objects in terms of their parameters and their relationships to other things. As a consequence of this, changing one item will result in the modification of all connected objects. Using BIM, it is possible to print in three dimensions models and buildings of varying sizes (Olsson et al., 2021).

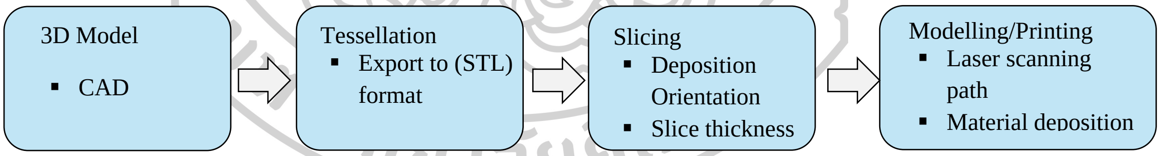

Figure 2.1 Three-dimensional printing workflow.
Source: Baigarina et al. (2023).

2.1.1 Three-dimensional printing technology development

Dr. Behrokh Khoshnevis is credited with making the first effort at 3D printing in the building business in 1995. According to Alzarrad and Elhouar (2019), Dr. Khoshnevis created three-dimensional ceramic pieces using the technique known as stereolithography. It was determined that the part's mechanical qualities needed to be improved, despite a complex ceramic component being constructed. Dr. Behrokh

Khoshnevis submitted a patent application in 1996 for the invention "Additive Fabrication Apparatus and Method." This patent describes an apparatus for manufacturing three-dimensional objects using the process of additive fabrication. The apparatus contains two control means for moving and positioning the nozzles, two supply means for conveying fluid materials to the nozzles, and two nozzles for delivering fluid materials. The fluid materials are carried to the nozzles by two supply means. Trowels, which enable the rapid fabrication of flat surfaces with high levels of accuracy, are included as an extra feature of the equipment. It is possible to build various forms with only two trowels instead of the several tools required for conventional plastering. It is made possible by the trowels. Figure 2.2 depicts the innovative apparatus developed by Dr. Khoshnevi.

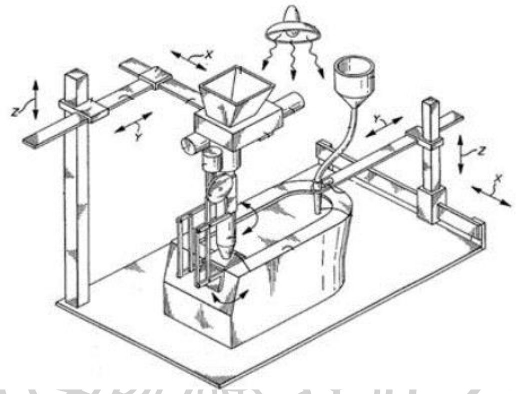

Figure 2.2 The first 3D printing apparatus.
Source: Alzarrad & Elhouar (2019).

2.1.2 Current situation of 3D printing technology

Baigarina et al. (2023) illustrated seven AM methods according to ASTM. It consists of Vat photopolymerization, material jet spraying, binder jet spraying, material extrusion, powder layer fusion, sheet lamination, and direct energy deposition, as shown in Fig. 2.3.

The descriptions of seven additive manufacturing (AM) methods are briefly explains below (Baigarina et al., 2023).

1) Material extrusion (ME) is putting material onto a substrate in successive layers while the substance is extruded via a nozzle. The method is known

as Fused Deposition Modelling (FDM). However, it has become the foundation for various home 3D printers available at more affordable prices.

2) The process of vat photopolymerization, often known as VP, involves the selective curing of a liquid light-activated polymer using a laser. This method can only be utilized with a select group of polymers and ceramics, and the resulting products have lower levels of mechanical quality when compared to those produced by powdered bed fusion and sheet lamination. However, the degree of surface quality and precision produced by this method is significantly greater. This process is best demonstrated by the stereolithography device, sometimes known as SLA.

3) Material jetting (MJ) refers to the process of depositing material droplets in a selected manner layer by layer. This approach is utilized by 3D Systems, Inc. in order to make UV-curable plastic dental prostheses with exceptional precision. These dental prosthetics include individualized crowns and copings.

4) Binder Jetting, often known as BJ, is the process of stacking a powdered product and painstakingly dousing each layer with a liquid binding agent to bind the granules together. The Massachuset Institute of Technology team that developed binder jetting used the 3D printing process (3DP) in their work. Standard materials include powdered polymers, ceramics, alloys with form memory, and metals.

5) When making a product with the powder bed fusion method, a laser, or electron beam is utilized to melt the powder and combine it into one solid mass before the process is complete; the end product is highly exact, and the manufacturing process is noticeably more efficient than directed energy deposition. This method is suitable for using various materials, including metals, ceramics, composites, polymers, and hybrid materials. This procedure consumes a significant amount of energy, and the result has a grainy appearance. In contrast to the process of material jetting, which frequently calls for utilizing some support system, this circumstance does not.

6) Sheet lamination (SL) is a process that uses numerous sheets of material to construct an item by molding and adhering them together. Sheet lamination is an example of the process known as laminated object manufacturing

(LOM), developed by Helisys Inc. After the paper sheets had been trimmed to size, they were glued into a LOM. In ultrasonic additive manufacturing, also known as UAM, which is marketed by Solidica Inc., things made of metal are manufactured via ultrasonic welding.

7) Direct Energy Deposition, often known as DED, is a method of fusing materials that use directed thermal energy to melt the material as it is being deposited to fuse it. One example of this technology is the laser-engineered net shaping approach developed at Sandia National Laboratories. This process is beneficial for restoring damaged metal components and was developed by Sandia National Laboratories.

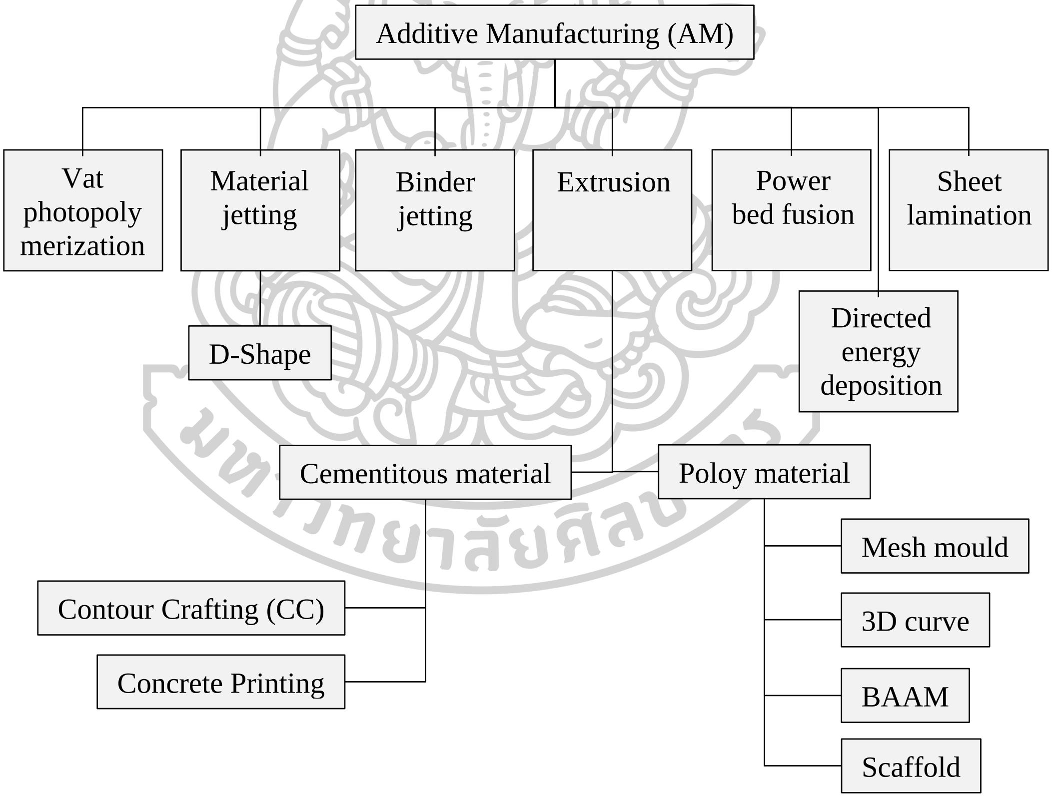

Figure 2.3 AM process classification.

Source: Baigarina et al. (2023).

2.2 The Technology Development in Construction Industry

Pegna developed the fundamental ideas for the application of 3D printing in the building industry in the early 1990s (Lim et al., 2012). In following years, contour crafting was created by Khoshnevis el al. (2006) of the University of Southern California. Extruding concrete using a gantry system is part of the contour sculpting process. The nozzle of the system has trowels that are attached to it, and these trowels help to make the surface of the concrete more even while it is being extruded. This sort of additive manufacturing was the first approach of its kind to be used for the fabrication of bespoke structures on-sit. Improved surface quality, increased manufacturing speed, and access to a wider range of material options are some of the benefits brought about by this technique (Olsson et al., 2019). The interfacial zones between the layers are weakened as a result of hydrostatic pressure and the poor mechanical characteristics of the extruded cement. This technology's limitations include the following: only vertical extrusions are feasible, it is complicated to implement for production, and only vertical extrusions are possible. Because of the prospective nature of contour crafting as a method to building on the Moon and Mars, NASA took an interest in the technique, and the organization awarded it their top prize (Davtalab et al., 2018). Concrete, polymer, and ceramic are the three types of materials that are utilized in the contour sculpting process.

2.2.1 Three-dimensional printing techniques in construction

In the realm of building and construction, the most common applications of three-dimensional printing are contour crafting (CC), concrete printing (CP), selective binder (cement) activation (SBA), selective paste intrusion (SPI), and D-shape. The first two varieties may be categorized as "Extruded Material Systems," whereas the subsequent three can be categorized as "Powder-Based Systems". In point of fact, concrete printing and contour crafting are rather comparable, as both of these processes involve the injection of a mixture (often mortar) via a nozzle in order to create the printed item. In this instance, the technique is analogous to that of the FDM methods; however, because the material in question is already fluid, it does not require any further heating. However, in order to feed the mix through the nozzle, you will need to use a pump. A dry combination of good aggregate and binder (cement) is locally activated through the use of the SBA process. This is done by selectively spraying the binder onto the packed particles, which results in the formation of a cement paste matrix around the aggregate particles. The technique known as selective paste intrusion involves injecting the binder, which is a paste composed of cement, water, and admixtures, into the particles in a controlled and selected manner. The cement paste need to be sufficiently liquid so that it may flow into the voids between the particles. When printing enormous things, the D-shape approach makes use of a printer that has a number of nozzles arranged in a line. Sand is used by the printer to build the thing up layer by layer, and a binder is sprayed on individual layers in a selective manner. The limitless sand that was around the printed layer is still there, and it is just providing temporary support for the structure. The binder is often a resin that has a reaction with a component in the particle bed that causes it to become harder. Figure 2.4 shows the concrete printing method.

Figure 2.4 Concrete printing.

Source: University of Johannesburg (n.d.).

2.2.2 Advantages of 3D printing in construction

El-Sayegh et al. (2020) categorized the advantages of using 3D printing in construction industry into two groups: constructability and sustainability advantages. Table 2.1 concludes the advanges.

Table 2.1 Three-dimensional printing adoption advantages.

No.	Description
Construction advantages	
1	Faster construction
2	Lower cost
3	More geometric freedom
4	Shorter supply chain
5	Improve productivity
Sustainability advantages	
6	Sustainability and eco-friendly structures
7	Less waste
8	Reduces formwork
9	Safer sites
10	Social

Source: El-Sayegh et al. (2020).

1) Faster construction

Clients can reap benefits from a shorter construction length, including an earlier start to the operations phase and the generation of revenues, a reduction in overhead expenses, and the release of resources for use in other projects. The capacity to make things more quickly is made possible by 3D printing. The pace of building is significantly quicker than with more conventional approaches. It is possible to print a house in just one day. Construction on a larger scale and manufacture in more significant quantities will both benefit from this. The use of automated building construction has various benefits, including increased construction speed and a greater level of individualization in the finished product. Utilizing 3 D printing technology may considerably cut down on the amount of time spent building. According to Wu et al. (2016), the printing time for a structural wall was cut in half, from 100 hours to 65 hours, thanks to the use of 3D printing.

2) Lower cost

The cost of building elements, as well as the cost of transporting materials and storing them, is lowered as a result of this innovation. The labor cost is minimized as a result of the fact that the machine only needs one operator. In the instance of the 3 D-printed office in Dubai, the laborers involved included seven employees to install construction components, 10 electricians, specialists to manage the MEP, and one person to oversee the printer. All of these workers were employed by the same company. According to Zhang et al. (2018), the labor costs associated with maintaining this office were sixty percent cheaper than those associated with traditionally constructed structures of the same size. Operations that required less manual work were also observed in a variety of sub-sectors within the Building and Construction industry. In addition to a decrease in the cost of labor, the use of 3 D printing leads to a reduction in the expenses associated with the installation and removal of formwork. The number of site engineers, along with a number of other positions, will be eliminated, which will result in a reduction in supervision expenses. In addition to this, a quicker construction time will result in reduced indirect costs.

3) More geometric freedom

The previous approaches are made obsolete by the technology, which enables greater geometrical and design freedom. One of the benefits that contribute to the growing interest in technology is the capability of designing and building buildings that cannot be created using any other method. The 3 D-printed home that was created in Denmark by the company 3D Printhuset was discussed before and was constructed without the use of straight lines, with the exception of the doors and windows. This was done to demonstrate the degree of geometrical flexibility. It is simple to print expensive curving buildings that are difficult to construct with other methods due to their complex shapes. Therefore, architects should have an open mind in order to increase their chances of making significant advancements in the design process. Meanwhile, this contributes to the realization of the confluence of arts and architecture. The 3 D printing technology makes it possible for architects and designers to create structures that would be challenging to fabricate using conventional methods of human construction.

4) Shorter supply chain

The supply chain can become more streamlined thanks to 3 D printing. By manufacturing products on demand, 3 D printing reduces the requirement for materials to have a lead time, which enables them to be delivered more quickly. Productivity goes up as a result of this procedure, and the number of late deliveries goes down. When raw earth resources are used, there is no longer any need for a lead period, which in turn reduces the length of the supply chain. AM of construction materials is one of the emerging advanced technologies that aim to minimize the supply chain in the construction industry through the autonomous production of building components directly from digital models without the need for human intervention or complicated formworks (Ghaffar et al., 2018). It is accomplished through the use of additive manufacturing (AM) construction materials, which is one of the emerging advanced technologies.

5) Improve productivity

Automation in the construction industry has demonstrated the ability to boost overall construction productivity. AM is viewed as a technique to overcome productivity issues that arise in the construction industry. Increasing amounts of pressure are being put on the construction industry to increase its efficiency and effectiveness, lowering its adverse effects on the environment, material consumption, and overall costs.

6) Sustainable and eco-friendly structures

Pursuing activities that satisfy the present's requirements without compromising future generations' capacity is an example of what is meant by the term "sustainability." Using sustainable design in the construction industry may improve product quality while lowering its overall impact on the surrounding environment.

The level of environmental friendliness of a building project may be evaluated using the LEED grading system and certification.

7) Less waste

The utilization of 3 D printing technology helps to cut down on the quantity of trash generated during the building process. Because this method is a form of additive manufacturing, the materials that are utilized are tailored to the output that is created; as a result, there is very little waste produced by the process. In addition, the process of 3D printing makes use of raw materials such as sand that are recyclable and reusable. According to Labonnote et al. (2016), it is anticipated that 3D printing may save between 30 and 60 percent of waste from the building industry. The amount of material waste and dust generated during the building erection process is significantly reduced due to the reduction in wet construction technologies. It supplies a resource-efficient building industry with lightweight structural components, which will assist in decreasing the development of waste, pollution, and the use of world resources. Because the printing process will only require the appropriate quantity of resources, this will result in the elimination of any excessive waste of materials, which will, in turn, reduce the negative effects that the manufacturing or building process has on the environment.

8) Reduced formwork

Additive manufacturing technology decreases in the amount of formwork. This step, which is essential in conventional buildings, is skipped; as a result, the waste that would have been produced by the formworks is discarded. When using AM construction, the building may be immediately molded and shaped on-site, eliminating the need for the wooden forms that are required when using traditional concrete [50]. Reduced usage of formwork has an effect on the environment since it results in less consumption of wood and, as a result, fewer trees being cut down (Camacho et al., 2018).

9) Safer sites

Safety is a significant problem in the construction business due to the fact that deaths and injuries sustained while working on construction projects result in enormous financial losses for affected individuals, companies, and communities. Because 3D printers can handle the majority of dangerous labor, this technology helps to cut down on the number of accidents and fatalities that occur on construction sites. This advantage is made possible by the fact that the construction process may be automated through the use of 3D printing. AM has the potential to offer services to the construction industry by lessening the risk of injury to employees who are on-site and by automating a number of the jobs that are performed in the construction sector.

10) Social

The application of 3D printing in building projects has the potential to improve society by altering the way construction work is carried out. In addition to this, it causes transformations to occur in labor structures, such as gender equality and a safer working environment, and it causes movements toward supply chains that are more digital and locally based. Since a substantial portion of the 3D printing process is highly automated, it is possible to significantly minimize the amount of human resources necessary for the building process. One of the primary advantages that 3D printing offers in the construction industry is the ability to cut down on the total number of employees. As a result of this decline in the workforce, new types of construction workers will emerge, each of which will require new skills in order to keep up with advances in technology.

2.2.3 Progress and examples of three-dimensional printing buildings

In the first generation of 3D concrete printers, the printing process involves the extrusion of very low-slump mortar intended to be self-supporting from a deposition head positioned on a gantry. This method is comparable to the FDM process. Although FDM is not the only method that has the potential to be applied in the building sector, it is the method of choice since it makes use of the least expensive resources and is thus preferred.

Since 2007, Dr. Richard Buswell and Professor Simon Austin have led a group of researchers at Loughborough University in the United Kingdom focused on developing 3D printing solutions for use in the building and construction sector (Holt et al., 2019). They are contributing to developing a supply chain for the necessary materials while working toward building and commercializing a 3D concrete printing robot. Skanska, a global leader in the construction industry, has joined forces with Loughborough University to accelerate the development of 3D printing technologies into a financially feasible building.

In 2014, the Chinese business WinSun printed ten primary residences in one day to illustrate how 3D printing might be utilized realistically (WinSun, 2016). It is stated that each construction could have been produced for less than US$5000 and that most of the components used were recycled. WinSun accomplished off-site manufacturing of the home components with the use of a big gantry-style printer and high-performance mortar. The finished components were then delivered to the job site and assembled in a manner analogous to conventional precast construction. WinSun demonstrated that 3D printing might one day be an effective method of building, even though the finish on the houses' elements was subpar compared to the standard precast concrete finish. The buildings were built quickly and affordably. However, the whole potential of 3D printing was not realized since the components still needed to be transported and assembled on-site. Figure. 2.5 shows an example of residential buildings made by WinSun.

Figure 2.5 Residential buildings of WinSun.
Source: Winsun (2016)

WinSun has demonstrated that 3D printing can be used to construct higher structures by erecting a five-story apartment building and a thousand-and-one-hundred square meter concrete palace, both of which come fully furnished inside. Approximately $160,000 in United States dollars was spent on printing the mansion. Since then, WinSun has shared the news that the Taiwanese real estate firm Tomson Group has given it the order to produce ten of these houses (Russon, 2015). The list of houses that WinSun has constructed now includes 80 and 130 m^2 residences with a courtyard designed in the Chinese style. The assembly process for each of these homes takes two days. The beauty of the printed pieces has been enhanced, even though architectural improvements have been made in the more recent WinSun structures compared to the early creations. The firm has developed facades that can be mounted to walls using screws. There are intentions to license their technology to be utilized in other countries, but the acceptance in China has required it to be speedier. Three years after showing its first 3D-printed structures, WinSun is constructing bus stops and public bathrooms (Aldama, 2017).

In 2013, DUS Architects announced their intentions to employ a 3D printer called the KamerMaker (which translates to "Room Maker" in English), see Fig. 2.6. This printer would produce a full-scale replica of an Amsterdam canal home. The group of people who were responsible for the project wanted to learn as they built the full-sized house, and they were able to raise the printing speed by a factor of three while they were working on it (the build started in 2014). When it approaches the end of its useful life, the structure is created from ecologically friendly plastic containing linseed oil and can be recycled by shredded into smaller pieces (Rosen, 2014). The same group of people developed an urban cabin in August of 2016, with a footprint of 8 square meters and a total volume of 25 cubic meters. The house has barely enough space for a bed, but it comes complete with a 3D-printed bathtub outside the cabin. These buildings, despite their diminutive size, can be printed rapidly and at little cost to provide emergency shelter. Furthermore, they can be removed and recycled once they are no longer required (Anusci, 2015).

Figure 2.6 3D-printed canal houses in Amsterdam.
Source: Rosen (2014)

In May of 2016, the Dubai government revealed a 3D printed office space that was 250 square meters in size and was placed within the Emirates Towers Complex in Dubai (Williams, 2016). During the course of 17 days, WinSun's gantry-style printer (6×336×312 m) and other, more manageable printers were utilized to produce the offices. However, only one person was needed to monitor the printing process. The various parts were printed in a plant owned by WinSun in China, and then they were assembled in Dubai. It was predicted that building the offices would cost around US$140,000, and the labor cost would be nearly half of what would be necessary for structures of a comparable size (Williams, 2016); see Fig. 2.7 for further information. Following the completion of construction, both the inside and exterior were given their finishing touches. Just before to the launch of the 3D printed office, which can be seen in Fig. 2.8, the government of Dubai made the announcement that they want to work toward the goal of having 25% of Dubai's structures produced utilizing 3D printing by the year 2030. The government plans to establish itself as a center for study into 3D printing in anticipation of the technology's potential to one day permeate all facets of life for the betterment of humanity. It is anticipated that the utilization of 3D printing technology will increase in Dubai by around 2% in 2019, and will continue to climb even higher over time dependent on the continued growth and dependability of 3D printed buildings (Charmernik, 2016).

Figure 2.73 D-printed commercial buildings in Dubai.

Source: Willams (2016)

Figure 2.8 Interior design in 3D-printed commercial buildings in Dubai.

Source: Charmernik (2016)

Companies like Cazza, which participated in the Dubai Futures Accelerators program and have subsequently relocated their headquarters to the United Arab Emirates as a result of Dubai's interest in 3D printing, have been drawn to the city as a result. In June of 2017, Cazza introduced its line of robotic construction 3D printers, see Fig. 2.9, with the goal of accelerating the building process without compromising safety or causing an excessive financial burden or negative impact on the environment. According to Saunder (2017), the printers can complete the construction of a home of 100 square meters in only one day, and the process only requires one worker to insert steel reinforcements between the layers. Cazza has also revealed that they intend to build a tower in Dubai that will be constructed using their 3D printing technology. The company anticipates that construction will begin in the year 2023.

Figure 2.9 Cazza’s robotic construction 3D printer.
Source: Saunders (2017)

Emerging Objects, located in the United States, is developing building components utilizing an entirely different technology and concentrating on the aesthetic advancements made possible by 3D printing. It is stated that the finished products are lightweight while also being toughened thanks to the use of fiber reinforcement. Emerging Objects provides customers with post-printing treatments, including sandblasted, glossy, and satin options. They have added utility to many of their goods, such as their interconnecting seismically resistant blocks and acoustic-dampening walls (Emerging Objects, n.d.). It is made possible by the enhanced form capabilities of 3D printing.

2.3 Technology Adoption Theory

According to Taherdoost (2018), several adoption models have been established to understand better the various aspects that impact the acceptance of technological advancements. The Technology-Organizational-Environment (TOE) framework focuses on accepting new technologies at the organizational level (Lippert & Govindarajulu, 2006). The most popular models for understanding the acceptance behavior of individuals are other variants of the Technology Acceptance Model (TAM) and the Unified Theory of Acceptance and Use of Technology (UTAUT) model. The Diffusion of Innovation (DOI) Theory may be used to investigate adoption behavior at both the individual and the business levels. It is essential to distinguish between the adoption of innovations by an individual and the adoption of innovations by an organization because the elements that impact the choice to adopt are different for each. In addition, the complexity of organizations is far higher than individuals (Oliveira et al., 2014). Organizational innovation is "the implementation of a new organizational method in the firm's business practices, workplace organization, or external relations." Competitive pressures occasionally drive businesses to adopt a particular innovation to maintain their competitive edge (Al-Zoubi, 2013). It is one of the key reasons for adopting such an organizational innovation, as it is one of the primary reasons for implementing any innovation. Therefore, one must also consider the surrounding environment when it comes to organizational innovations. The TOE framework, TAM, and DOI theory at the company level are the most relevant frameworks for this study since the research aims to explore the adoption of 3D printing in the construction sector, and the focus of the dissertation is thus on construction businesses. These models are frequently utilized in organizations' research about the adoption and spread of innovations.

2.3.1 Diffusion of Innovation

One of the oldest ideas in social science is called the Diffusion of Innovation (DOI) Theory, proposed by E.M. Rogers in 1962. It was initially used in communication to explain how, over time, an idea, or product gathers momentum and diffuses (or spreads) among a particular population or social system (Indiafreenotes, 2020). Due to this diffusion process, individuals within a social system will eventually accept a novel concept, behavior, or product. A person is said to have adopted something when they do something differently than they did in the past, such as when they buy or use a new product, learn and execute a new behavior, etc. The concept, activity, or product in question must initially strike the individual as novel or pioneering for them to accept it. It allows for the possibility of dispersion to take place.

The process by which some individuals are more likely to accept a new idea, behavior, or product (also known as "innovation") does not occur instantaneously in a social system; instead, it is a process by which some people are more likely to embrace the innovation than others. According to researchers, the traits of people who accept a new technology early on are distinct from those who adopt a technology later on. When trying to sell an innovation to a particular group of people, it is essential to have a deep understanding of the characteristics of that group of people that will either facilitate or obstruct the adoption of the innovation. There are five identified adopter types, and while the vast majority of people in the general public tend to fit somewhere in the middle categories, it is still essential to understand the characteristics of the demographic you are trying to reach. When advertising an invention, many tactics are utilized to appeal to the various kinds of adopters, see Fig. 2.10.

Innovators strongly desire to test out a new idea before anybody else. They are not afraid of taking risks and are open to receiving further information. These individuals have a high tolerance for taking chances and are frequently pioneers in developing novel concepts. Minimal effort is required on our part.

Early Adopters are those who are thought leaders in their respective communities. They are excited by prospects for change and love taking on leadership responsibilities. They know the necessity of change and easily incorporate novel concepts. How-to guides and information sheets on the implementation are examples of strategies that may be used to appeal to this audience. They do not require knowledge to be persuaded to alter their behavior.

Early Majority is the people that fall under this category are not typically leaders but are known for being the first to embrace novel concepts. To be prepared to adopt a new invention, they often want proof that the innovation is successful. Success stories and evidence that the creation is beneficial are strategies that may be utilized to appeal to this audience.

Late Majority - These individuals resist change and will only accept a new idea once most people have experimented. Information about the number of other people who have tried and successfully embraced the invention is one of the strategies that may be used to appeal to this audience.

People who adhere to the values of conservatism and traditionalism are referred to as *laggards*. They are reluctant to adapt to new circumstances and represent the most challenging demographic to win over. Statistics, arguments based on fear, and pressure from members of other adopter groups are all strategies that might be used to win over members of this community.

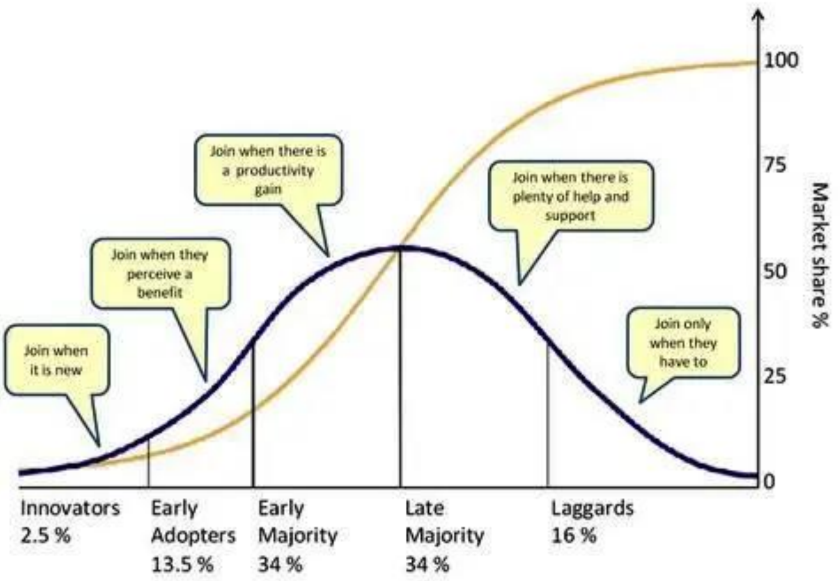

Figure 2.10 Diffusion of innovation.

Source: Indiafreenotes (2020)

2.3.2 Main factors influence diffusion of innovation

It is necessary to expand on the five critical factors of acceptance behavior that were previously described (relative advantage, compatibility, complexity, observability, and trialability). The qualities of individual leaders, internal organizational structure features, and external characteristics of the organization will all be connected to adoption behavior at the firm level (Rogers et al., 2014). These relationships are presented in a scheme in Fig. 2.11, found below. Following is an explanation of these three independent variables in further depth, DOI theory applied to the organizational level.

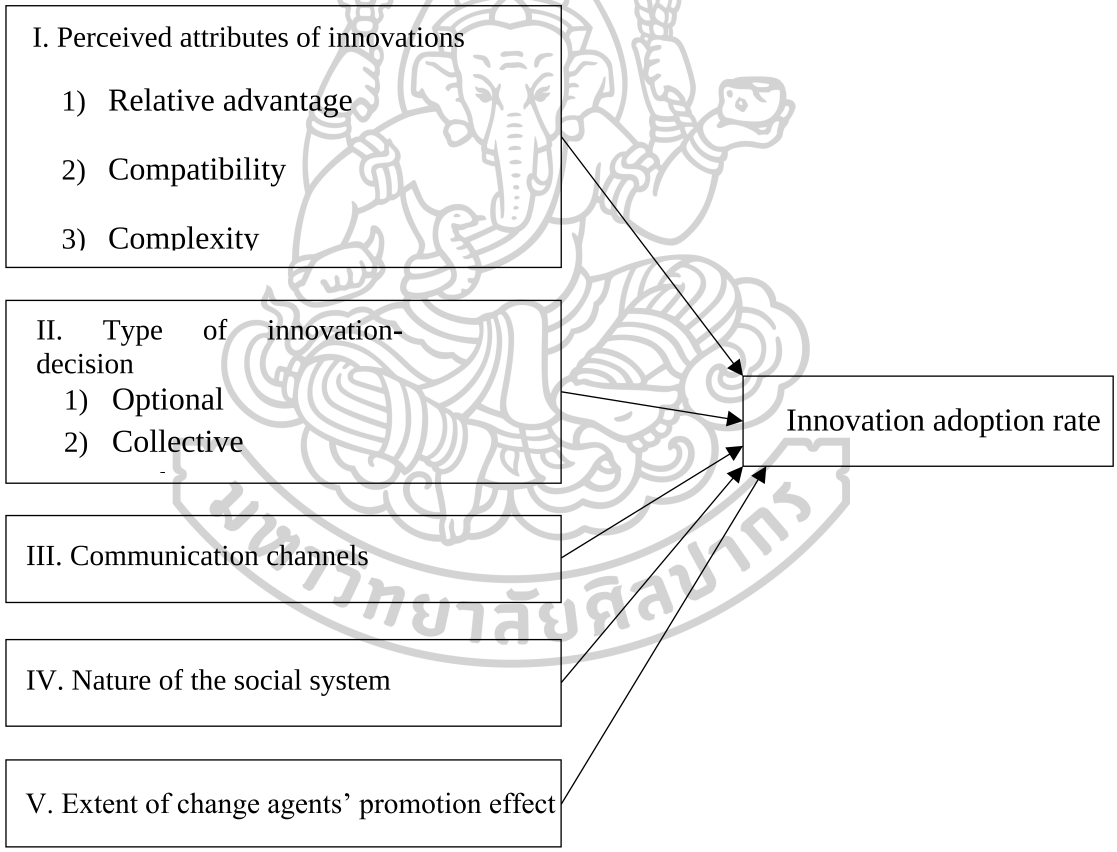

Figure 2.11 Innovation adoption rate.

Source: Rogers (2014)

1) Relative advantage: The extent to which the invention is judged to be superior to the practice that is already being used.

2) Compatibility: The extent to which the invention is seen to be compatible with the ideals of the society, the concepts that have come before it, and/or the needs that are now being perceived.

3) Complexity: The degree to which a new technology is difficult to apply or comprehend is referred to as its simplicity.

4) Trialability: The extent to which the invention can only be sampled on a limited basis for experience.

5) Observability: The extent to which the benefits of an invention may be observed by those who could eventually embrace it.

2.3.3 Technology acceptance model

Fred Davis presented what would become known as the technology acceptance model (TAM) more than a quarter of a century ago (in 1985). Since then, it has been the model of choice for researching the elements that influence consumers' adoption of new technology (Marangunić & Granić, 2015). The TAM presupposes that perceived ease of use and perceived usefulness play a mediating function in the complicated relationship that exists between the characteristics of the system (external variables) and the prospective utilization of the system. The theory of action management (TAM), which is rooted in psychology and was derived from the theory of reasonable action (TRA) and the theory of planned behavior (TPB), has been at the forefront of describing how people interact with technology. There is no way to conduct exhaustive and methodical study in the subject if one does not have a solid grasp of the model's history, its evolution, the changes it has through, and the constraints it places on its use.

As illustrated in Fig. 2.12, Fred Davis proposed that the actual use of the system is a reaction that can be explained or anticipated by user motivation. User motivation, in turn, is directly impacted by an external stimulus consisting of the actual system's characteristics and capabilities.

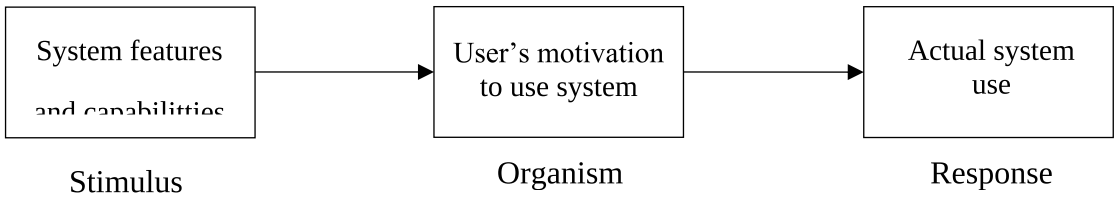

Figure 2.12 TAM conceptual model.

Source: Chuttur (2009)

2.3.4 Technology-Organizational-Environment Framework

Tornatzky and Fleischer (1990) established the TOE framework to understand the process of companies adopting technological innovation. This theory acknowledges three fundamental aspects that impact the adoption decisions of innovations in companies: the technical context, which is also covered in the DOI theory, but on top of that, also the environmental context. These three contexts are the technical context, the organizational context, and the ecological context, see Fig. 2.13.

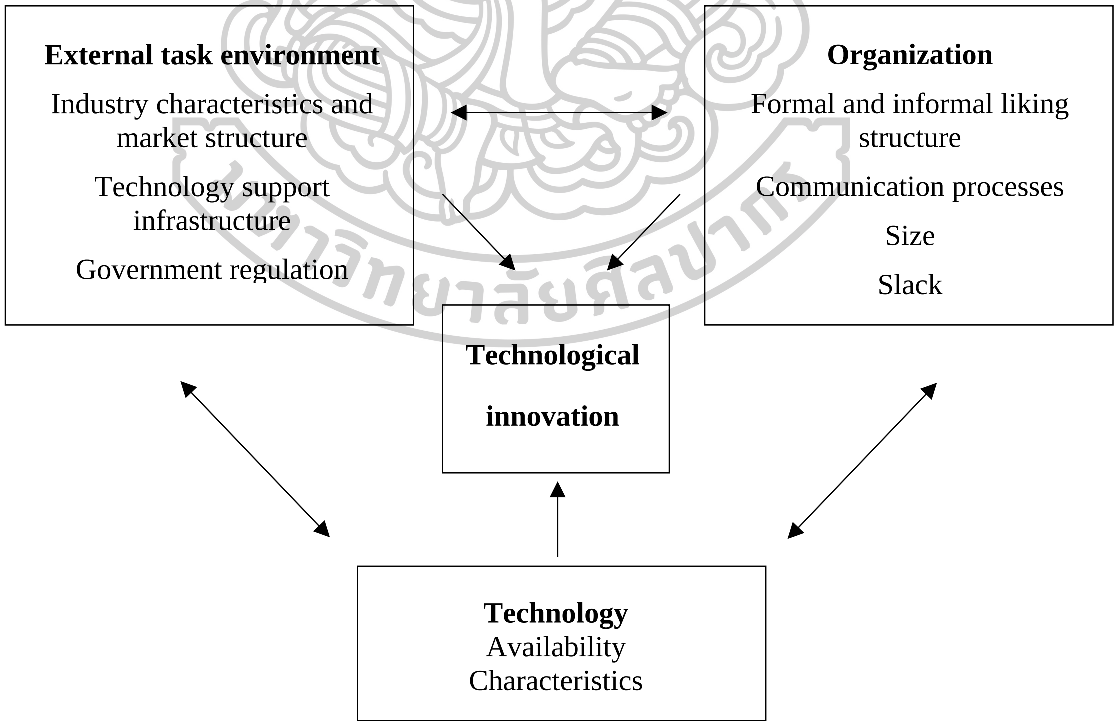

Figure 2.13 TOE framework.

Source: Van Dyk et al. (2019)

1) Technological context

The technical context takes into account all of the technologies that are pertinent to the company, including those presently in use at the company and those that are accessible on the market but are not yet being utilized by the company. Because they restrict the breadth and speed of technological change that may be undertaken by a company, the technologies that are already in use inside a company are a crucial component of the adoption process. Existing innovations that have yet to be implemented at the company can also impact innovation since they define feasible boundaries and demonstrate how technology can help businesses develop and adapt.

Three categories of innovations may be found among those originating from outside the company: innovations that produce incremental, synthetic, or discontinuous changes. Innovations that result in cumulative change result in the addition of additional capabilities to or iterations of already existing technology. These incremental improvements offer the adopting company the lowest risk level and the fewest opportunities for change. A few examples of this would be upgrading from an older version of an enterprise resource planning (ERP) system to a more recent version of the same design or switching from computer monitors that use cathode ray tubes (CRTs) to ones that use liquid crystal displays (LCDs). Innovations that produce synthetic change represent a middle ground of modest difference, in which pre-existing ideas or technology are integrated in an original way to create new results (Baker, 2012).

2) Organizational context

The linking structures between workers, intra-firm communication procedures, company size, and the amount of spare resources are all examples of the organizational context. The organizational context relates to the features and resources of the firm. The adoption and implementation decisions that are made are impacted by this environment in several different ways. Creativity is fostered through methods that link different internal subunits of the organization or bridge different internal borders. Adoption is connected to informal connecting agents, including product champions, boundary spanners, and gatekeepers. Examples of such systems are cross-functional teams and individuals with official or informal linkages to other departments or partners in the value chain.

On a broader scale, research has been conducted to investigate the link between organizational structure and the process of innovation adoption. There is a correlation between adoption and organizational structures that are organic and decentralized. Companies that use these systems emphasize teams, allow for some wiggle room in the obligations individuals are expected to fulfill, and encourage contact between departments and communication along reporting lines. Other research on organizational structure suggests that while organic and decentralized systems may be best suited to the adoption phase of the innovation process, mechanical (rather than organic) forms, with their emphasis on formal reporting relationships, centralized decision-making, and clearly defined roles for employees, may be best suited to the implementation phase of the innovation process. It is because mechanical forms emphasize formal reporting relationships, centralized decision-making, and clearly defined roles for employees (Baker, 2012).

3) Environmental context

The environmental context consists of the structure of the industry, the availability (or lack thereof) of technological service providers, and the regulatory environment. Several different approaches have been taken in the study of industry structure. For instance, fierce rivalry encourages more people to embrace innovative practices. Additionally, strong enterprises within the value chain have the ability to inspire innovation among other partners.

In terms of the life cycle of an industry, it has been observed that businesses operating within industries that are undergoing rapid expansion innovate at a faster rate. On the other hand, innovation processes may be more straightforward in established or waning sectors. Some companies are taking advantage of the downturn in their industry to innovate by implementing new efficiency efforts or expanding into other business areas. Some businesses may forgo investing in innovation in order to cut expenses. It is still necessary to do empirical research in order to verify the assumptions made regarding the connection between the life cycle of an industry and the adoption of innovations.

The underlying infrastructure that technology relies on also has an effect on innovation. Companies that are required to pay high rates for skilled workers are frequently forced to create labor-saving technology in order to stay competitive. The availability of trained workers, as well as the availability of consultants and other providers of technical services, both contribute to the growth of innovative ideas. Last but not least, the impact that government regulation has on the innovative process can be either positive or negative. When governments impose additional limits on an industry, such as requiring pollution-control devices for energy businesses, creation is practically required for those energy firms. This is the case when governments do things like require pollution-control devices for energy firms.

In a similar vein, severe safety and testing standards can be a barrier to innovation in a variety of different businesses. The cost of innovation may be rather high, for example, in the building industry, where new materials must first undergo thorough testing before they can be utilized, or in the agricultural industry, where new kinds of crops must be copyrighted and licensed before they can be sold. Another illustration of this may be seen in the banking industry, where regulations about consumer privacy may force financial institutions to refrain from developing new access methods for customer accounts. Therefore, governmental regulation has the potential to either stimulate or stifle innovative activity (Baker, 2012).

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Research Strategy

The strategy for this research was devised after examining data and literature that had been done so previously. Because of the breadth and depth of the information that is readily available, it is possible to carry out an exhaustive research report and come to reasoned conclusions. Even though this is a well-established research topic, this paper aims to examine both the local and global implications of 3D printing of building components to estimate the total impact on the Kunming construction industry and economy.

3.2 Research Approach

The most common approach to study is called survey research. In order to develop a full review and get to the most accurate conclusion possible, this will be treated as a quantitative study. The utilization of numerical data is made possible via the usage of this concurrent technique of research.

3.3 Data Collection and Tools

The construction project managers overseeing building projects in Kunming are the intended recipients of this survey. Additionally, engineering consultants, academic staffs, and government engineers are also the target. Yunan province's capital and largest city, Kunming, has an urban area that spans around 4,013 km^2 and a metropolitan region that spans approximately 2,622 km^2 combined. The construction projects encompass a variety of building types, including residential, commercial, and public structures. The questionnaire will be delivered through e-mail, and a follow-up phone call will be necessary in the event that a response is delayed. During the period of October 2023 to December 2023, the survey will be carried out utilizing the snowball sampling method.

The populaiton size identifying is not easy. The questionnaire will be sent to 400 samples. The Kaiser-Meyer-Olkin (KMO) and measure of sampling adequacy are conducted to test the data stability, the sampling adequacy, as shown below.

$$MSA_j = \frac{\sum_{k\neq j} r_{ik}^2}{\sum_{k\neq j} r_{jk}^2 + \sum_{k\neq j} p_{jk}^2} \tag{3.1}$$

$$KMO = \frac{\sum_{j\neq k}\sum r_{jk}^2}{\sum_{j\neq k}\sum r_{jk}^2 + \sum_{j\neq k}\sum p_{jk}^2} \tag{3.2}$$

where r_{jk} is the correlation between the variable in question and another, p_{jk} is the partial correlation.

3.4 Data Analysis

First of all, the Cronbach's α coefficient will be used to assess the reliability of the returing questionnaires.

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum_{i=1}^{k}\sigma_y^2}{\sigma_x^2}\right) \tag{3.3}$$

where k is the number of items in the measure, σ_y^2 is the variance associated with each item, and σ_x^2 is the variance associated of the total scores.

Then, the data is examined the normal distribution by using Kolmogorove-Smirnov test (K-S test) at 95% confidence. The empirical distribution function F_n for n independent and identically distributed (i.i.d.) ordered observatons X_i is defined as

$$F_n(x) = \frac{1}{n}\sum_{i=1}^{n} 1_{(-\infty,x]}(X_i) \tag{3.4}$$

where $1_{(-\infty,x]}(X_i)$ is the indicator function, equal to one if $X_i \leq x$ and equal to zero otherwise.

The Kolmogorov-Smirnov statistic for a given cumulative distribution function $F(x)$ is

$$D_n = \sup_x |F_n(x) - F(x)| \tag{3.5}$$

where $\sup_x$ is the supremum of the set of distance. Intuitively, the statistic takes the largest absolute difference between the two distribution functions across all x variables.

3.5 Research Procedure

Figure 3.1 shows the steps of this research project.

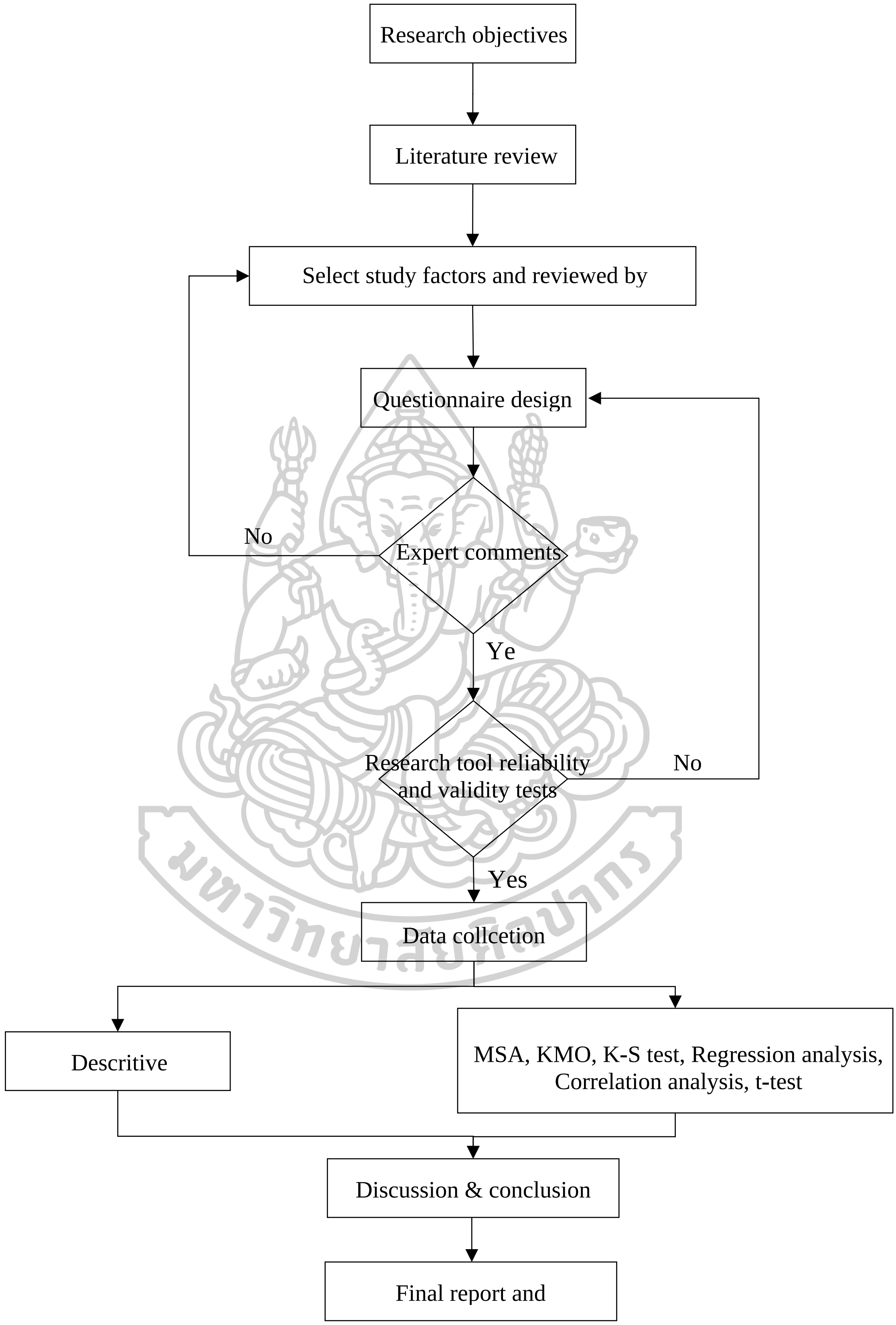

Figure 3.1 Research process flowchart

CHAPTER 4

RESULT AND ANALYSIS

A questionnaire was designed to collect data from staff in construction projects in Kunming. There were three sections to the questionnaire. Section 1 is about the respondent demographic information, e.g., age, position, and experience. Section 2 asks the current situation of 3D printing technology application in construction projects. Section 3 asks about the factor's importance on a 5-point Likert scale: 1 is ‘strongly disagree,’ 2 is ‘disagree,’ 3 is ‘neutral,’ 4 is ‘agree,’ and 5 is ‘strongly agree.’ The contents of the questionnaire are grouped into nine groups: relative advantages, complexity, trialability, compatibility, absorptive capacity, external pressure, uncertainty, supply-sided benefits, and demand-side benefits. The detailed contents are shown in the tables below.

Table 4.1 Section 1 of the questionnaire.

No.	Question
1	What is your gender?
2	How old are you?
3	What is your education level?
4	What is your job position?
5	How much your salary?
6	How long you have been working? (Include previous jobs)
7	What is your education major?
8	What are working at?
9	Do your construction project is in Kunming?
10	How big is your construction project?
11	How many employees in your construction site?

Table 4.1 Section 1 of the questionnaire. (continued)

No.	Question
12	Is your construction project state-owned?
13	What is your position in the construction project?
14	How long you have been working in construction industry?
15	Do your construction project applying 3D printing technology?

Table 4.2 Section 2 of the questionnaire.

No.	Question
16	What type of 3D-printing technology you use in your construction site?
17	Is it a good investment for 3D printing technology?
18	Does 3D printing technology improve your construction project performance?
19	Do you need to extend 3D printing technology in other construction sites or other phases?
20	Why do you not use 3D printing technology in your construction site?
21	Do you have staff who know well in 3D printing technology?
22	Are investment and maintenance costs significant in using 3D printing on construction sites?
23	What is the level of your construction site performance? (In general).

Table 4.3 Section 3 of the questionnaire.

No.	Content
Relative advantages	
24	3D printing can reduce construction time.
25	3D printing can improve material usage.
26	3D printing can reduce construction cost.
27	3D printing can reduce manpower in construction projects.
28	3D printing can construction quality problem.

Table 4.3 Section 3 of the questionnaire. (continued)

No.	Content
Complexity	
29	3D printing application is simple.
30	Digital construction process is simple.
31	Computer-aided design process in construction industry is simple.
32	Using and maintaining 3D printer is simple.
Trialability	
33	3D printing yields acceptable tolerances.
34	The properties of 3D printing materials are predictable.
35	3D printing products are still good in the long term.
Compatibility	
36	3D printing can match with conventional construction.
37	3D printers can make most design elements.
38	3D printing is flexible enough for different construction needs.
Absorptive capacity	
39	3D printing needs the knowledge, skills, and expertise of workers.
40	Most of the workers have a good attitude toward 3D printing.
41	Extensive cooperation with other companies or research institutes is required.
External pressure	
42	Lack of knowledge about 3D printing in construction.
43	Lack of skilled workers for using 3D printing.
44	Lack of 3D printing suppliers who are trustable.

Table 4.3 Section 3 of the questionnaire. (continued)

No.	Content
Uncertainty	
45	3D printing technology is still in the developing phase.
46	There is a side effect in using 3D printing in the construction industry.
47	There is a skeptical concern about the environmental impacts of 3D printing.
Supply-side benefits	
48	Precast and assembly activities are reduced.
49	3D printing simplifies the construction processes.
50	3D printing reduces the need for transportation.
Demand-side benefits	
51	Quick response to customer demand change is possible.
52	Customized products with plausible prices are possible.
53	The collaboration with customers and suppliers is integrated.

The Item Objective Congruence (IOC) is employed to validate the questionnaire. It is determined by analyzing the collected data from three experts. The IOC calculation is shown in Appendix B.

There were 268 respondents in the data collection. It accounts for a 67.3% return rate. Normal distribution was tested through Kolmogorov-Smirnov (K-S) test at 95% confidence for section 3 of the questionnaire. The result shows that Komogorov-Smirnov statistics are non-significant (significance is > 0.05 in all vairables), which indicates that they are normally distributed, see Table 4.4.

Table 4.4 Komogorov-Smirnov (K-S) test.

Category	$\bar{x}$	S.D.	K-S test		Result *
			Statistic	Sig.	
Relative advantages	3.98	0.84	0.280	0.141	Accept H_0
Complexity	2.84	0.75	0.300	0.146	Accept H_0
Trialability	3.36	0.99	0.248	0.519	Accept H_0
Compatibility	3.28	0.65	0.252	0.494	Accept H_0
Absorptive capacity	4.86	0.84	0.248	0.522	Accept H_0
External pressure	4.05	0.74	0.269	0.389	Accept H_0
Uncertainty	3.95	0.96	0.244	0.545	Accept H_0
Supply-side benefits	4.13	0.70	0.262	0.433	Accept H_0
Demand-side benefits	3.94	0.97	0.250	0.507	Accept H_0

* Please note that H_0 = the data distribution is normal.

Additionally, to confirm that the test is consistent, Cronbach's alpha coefficient is calculated based on the collected data. It has shown that α =0.71 which means the test was acceptable.

4.1 Demographic Data Analysis

The significant demographic data are presented in this section. Some data are incomplete, for example, the size of the company in terms of money and the number of employees. Thus, some demographic data are presented in Fig. 4.1 to 4.4.

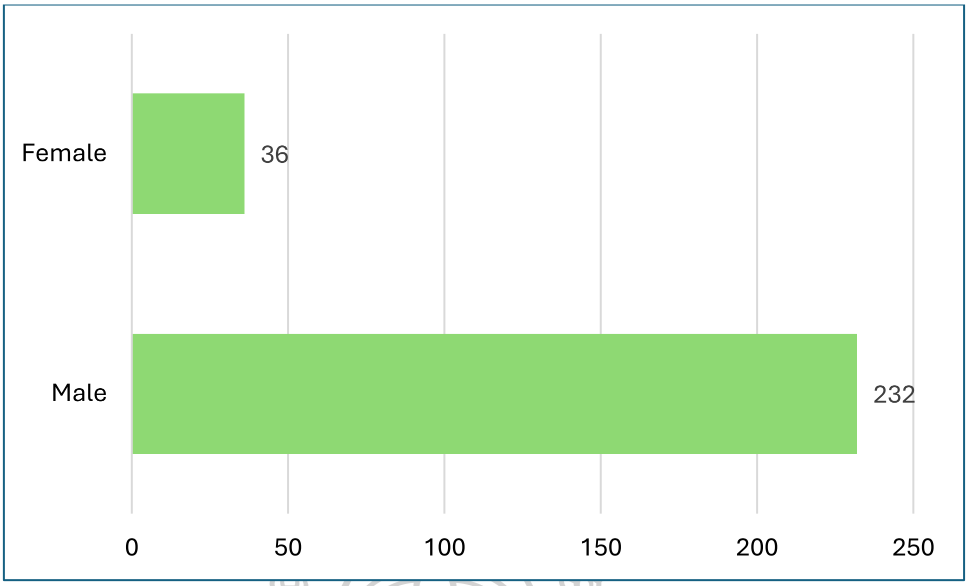

Figure 4.1 Gender of respondents.

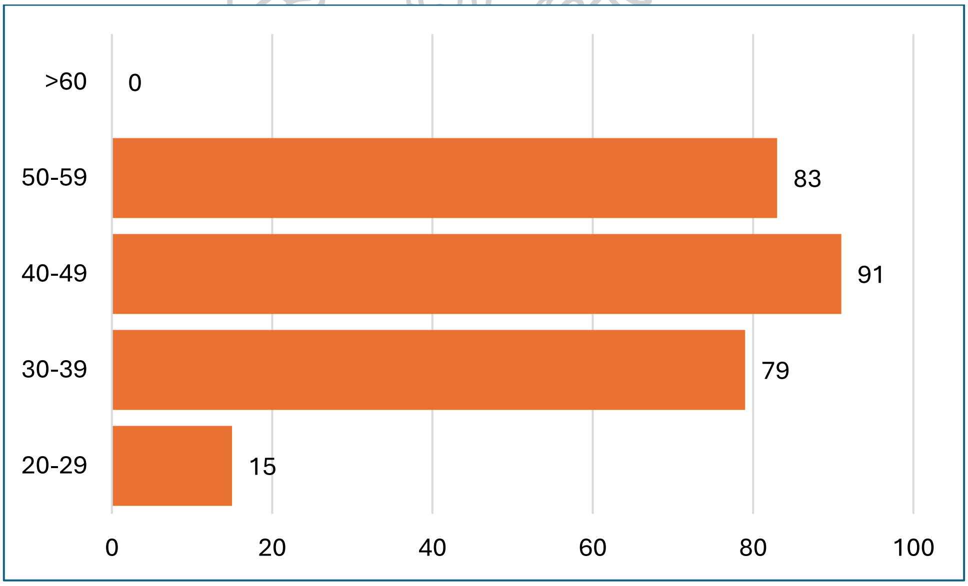

Figure 4.2 Age of respondents.

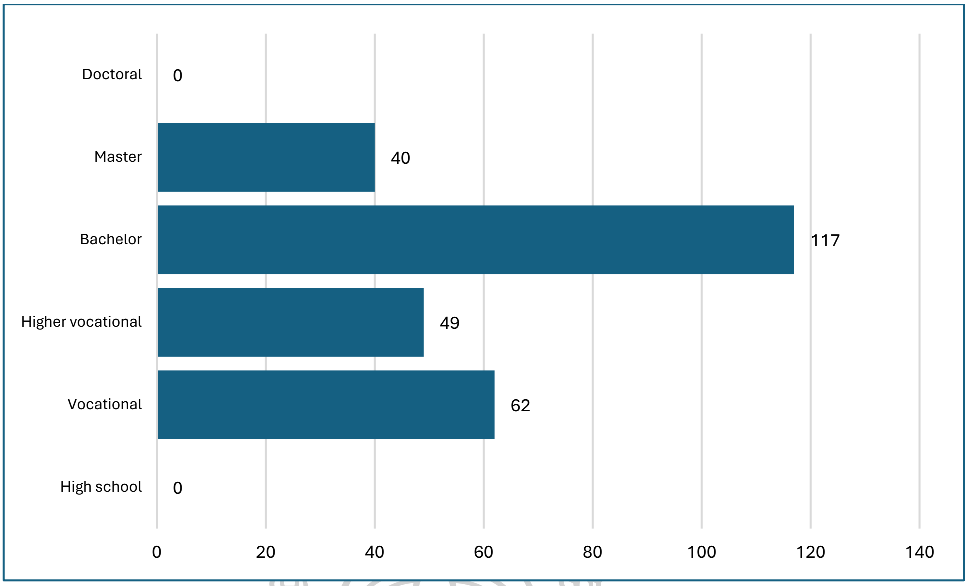

Figure 4.3 Education of respondents.

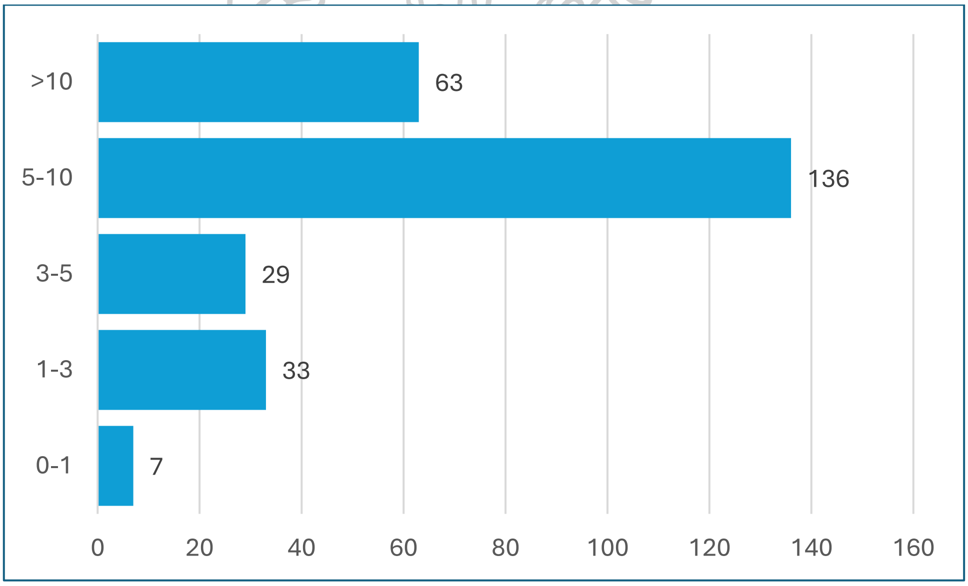

Figure 4.4 Experience of respondents.

From Fig. 4.1, most of the respondents were male, 88.05%. The age was between 30 and 59 years old, 94.40%, see Fig. 4.2. Figure 4.3 shows that the respondents hold a bachelor's degree 117 from 268, 43.65%. It was good that most of them had 5 to 10 years of experience in the construction industry, 50.75%, see Fig. 4.4. Please note that the working experience was accounted for working in the construction industry only.

4.2 Current Situation of 3D Printing Technology Adopting

Section 2 of the questionnaire investigates the current situation of three-dimensional technology implementation. Questions 15 to 23 asked about the respondents' application of 3D printing technology. It was found that 11.9% of the respondents apply 3D printing technology in their construction projects. Most of them agree it is a good investment, with 71.8% of the respondents implementing this technology. They plan to deploy the technology in other company construction sites in the future.

Nevertheless, 88.1% of the respondents are not using 3D printing technology. The main reason is the lack of skilled workers who can work with the new technology. Additionally, industrial-scale 3D printing is still high cost. Table 4.5 shows the details of section 2 data.

Table 4.5 Descriptive data analysis for section 2.

No.	Question	Choice	Frequency	Percent (%)
15	Do your construction project applying 3D printing technology?	Yes	32	11.9
		No	236	88.1
16	What type of 3D-printing technology you use in your construction site?	-	-	-
17	Is it a good investment for 3D printing technology?	Yes	23	71.8
		No	9	28.1
18	Does 3D printing technology improve your construction project performance?	Yes	30	93.8
		No	2	6.2
19	Do you need to extend 3D printing technology in other construction sites or other phases?	Yes	27	84.4
		No	5	15.6
20	Why do you not use 3D printing technology in your construction site?	-	-	-

Table 4.5 Descriptive data analysis for section 2. (continued)

No.	Question	Choice	Frequency	Percent (%)
21	Do you have staff who know well in 3D printing technology?	Yes	12	5.1
		No	221	94.9
22	Are investment and maintenance costs significant in using 3D printing on construction sites?	Yes	229	97.0
		No	7	3.0
23	What is the level of your construction site performance? (In general).	High	16	6.8
		Middle	198	83.9
		Low	22	9.3

Please note that questions 16 and 20 are open questions. Thus, they should be shown in Table 4.5.

4.3 Potentials and Challenges of Technology Adopting

Table 4.6 shows the statistical analysis of the respondents' opinions corresponding to section 3 of the questionnaire. Respondents who do not use 3D printing technology answered these questions. Thus, the number of respondents is 268.

Table 4.6 Descriptive data analysis for section 3.

No.	Content	$\bar{x}$	S.D.
	Relative advantages	**3.98**	**0.84**
24	3D printing can reduce construction time.	4.32	0.82
25	3D printing can improve material usage.	4.11	0.73
26	3D printing can reduce construction cost.	3.53	0.65
27	3D printing can reduce manpower in construction projects.	4.01	1.01
28	3D printing can construction quality problem.	3.95	0.95

Table 4.6 Descriptive data analysis for section 3. (continued)

No.	Content	$\bar{x}$	S.D.
	Complexity	**2.84**	**0.75**
29	3D printing application is simple.	2.87	0.71
30	Digital construction process is simple.	2.65	0.43
31	Computer-aided design process in construction industry is simple.	2.98	0.84
32	Using and maintaining 3D printer is simple.	2.86	0.92
	Trialability	**3.36**	**0.99**
33	3D printing yields acceptable tolerances.	4.12	0.94
34	The properties of 3D printing materials are predictable.	3.01	1.05
35	3D printing products are still good in the long term.	2.94	0.98
	Compatibility	**3.28**	**0.65**
36	3D printing can match with conventional construction.	2.75	0.44
37	3D printers can make most design elements.	3.98	0.73
38	3D printing is flexible enough for different construction needs.	3.12	0.74
	Absorptive capacity	**3.86**	**0.84**
39	3D printing needs the knowledge, skills, and expertise of workers.	4.21	0.65
40	Most of the workers have a good attitude toward 3D printing.	3.27	0.99
41	Extensive cooperation with other companies or research institutes is required.	4.11	0.84

Table 4.6 Descriptive data analysis for section 3. (continued)

No.	Content	$\bar{x}$	S.D.
	External pressure	**4.05**	**0.74**
42	Lack of knowledge about 3D printing in construction.	3.98	0.66
43	Lack of skilled workers for using 3D printing.	4.05	0.73
44	Lack of 3D printing suppliers who are trustable.	4.11	0.81
	Uncertainty	**3.95**	**0.96**
45	3D printing technology is still in the developing phase.	4.15	1.13
46	There is a side effect in using 3D printing in the construction industry.	3.73	0.98
47	There is a skeptical concern about the environmental impacts of 3D printing.	3.98	0.72
	Supply-side benefits	**4.13**	**0.70**
48	Precast and assembly activities are reduced.	4.24	0.66
49	3D printing simplifies the construction processes.	4.13	0.75
50	3D printing reduces the need for transportation.	4.03	0.39
	Demand-side benefits	**3.94**	**0.97**
51	Quick response to customer demand change is possible.	4.01	1.02
52	Customized products with plausible prices are possible.	4.02	0.73
53	The collaboration with customers and suppliers is integrated.	3.79	1.13

From Table 4.6, the maximum average is supply-sided benefits, 4.13. The second rank is external pressure, 4.05. The minimum average is complexity, 2.84. Additionally, the coefficient of variations is between 0.154 and 0.348. Tables 4.7 and 4.8 show the analysis of the nine groups' variance with the significance level (α) = 0.05.

Table 4.7 Analysis of variance on nine-group factors: summary.

Groups	Count	Sum	Average	Variance
1	29	138	4.75862069	7.261083744
4.32	29	106.82	3.683448276	0.28780197

Table 4.8 Analysis of variance on nine-group factors.

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	16.7619	1	16.7619	4.4409	0.0395	4.0129
Within Groups	211.3688	56	3.7744			
Total	228.1307	57				

Table 4.8 indicates that the nine-group factors are significantly different, p-value = 0.039 < 0.05. Accordingly, the average scores can be used to rank the supremacy of the factors. As a result, the potential of adopting concrete 3D printing technology in the construction industry has supply-side benefits and relative advantages. This technology can eliminate precise and assembly activities, simplify the construction process, reduce transportation operations, improve material usage, reduce cost, reduce the required workforce, and improve construction quality.

On the other hand, the external press's adoption of technology presents challenges. They must gain knowledge and skilled workers who can work with 3D printers. Furthermore, environmental impact must be evident during the construction and end-of-life phases of the product life cycle.

CHAPTER 5

CONCLUSION

5.1 Conclusion

This study investigated technology adoption factors in the case of three-dimensional printing technology in Kunming's construction industry. The result revealed that this technology facilitates supply-side benefits. It allows for the reduction of precast and assembly activities and also diminishes the construction processes and transportation operations. The respondents' opinion showed that the threat of adopting this technology was a lack of knowledge and skilled workers who can operate this operation. Furthermore, its materials and processes must be environmentally friendly.

There were few construction projects implementing 3D printing technology. The technology is acceptable in terms of investment, and construction performance improvement. On the other hand, the challenges of technology adoption are the lack of skilled workers who can work with 3D printers, and the initial investment is high. The high initial investment balks small and medium construction companies from using 3D printing technology.

5.2 Recommendations

This study was limited to Kunming's construction industry, which may not be referred to other areas. Furthermore, the economic situation also affects to the respondents' opinion. Consequently, the result may vary by time of study. The next investigation, we will do more statistical analysis, especially, the inference statistical analysis must be conducted rigorously.

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APPENDIX

APPENDIX A

Questionnaire

Questionnaire

Three-dimensional Printing Technology Adoption of

Construction Industry in Kunming,

The People's Republic of China

Mr. Zhikang Zhou

Engineering Program in Engineering Management

Department of Industrial Engineering and Management

Graduate School, Silpakorn University

This questionnaire consists of 3 sections of questions as follows:

Section 1: Demographic data of the respondents.

Section 2: Current situation of 3D-printing adoption in construction sites.

Section 3: Questions about the measurement items of potentials and challengers of 3D printing technology adoption.

Thank you very much for your cooperation. The data are kept secret and unopened to a third-party organization. The purpose of this study is academic only.

Section 1: Demographic data

No.	Question	Answer
Q1	What is your gender?	☐ Make ☐ Female
Q2	How old are you?	☐ 20-29 Years Old ☐ 30-39 Years Old ☐ 40-49 Years Old ☐ 50-59 Years Old ☐ 60 and older
Q3	What is your education level?	☐ High school ☐ Vocational ☐ Higher vocational ☐ Undergraduate ☐ Master degree ☐ Doctoral degree
Q4	What is your job position?	
Q5	How much your salary?	☐ less than 4000 Yuan ☐ 4,001 – 7,000 Yuan ☐ 7,001 – 10,000 Yuan ☐ 10,001 – 14,000 Yuan ☐ 14,000 Yuan or more
Q6	How long you have been working? (Include previous jobs)	☐ 0-1 year ☐ 1-3 years ☐ 3-5 years ☐ 5-10 years ☐ More than 10 years
Q7	What is your education major?	………………….

No.	Question	Answer
Q8	What are working at?	□ Construction project □ Academic staff □ Consulting company □ Government agency <u>If you are not working in construction projects, you can skip to Section 3.</u>
Q9	Do your construction project is in Kunming?	□ Yes □ No
Q10	How big is your construction project?	………………..RMB (estimate)
Q11	How many employees in your construction site?	……………….employees
Q12	Is your construction project state-owned?	□ Yes □ No
Q13	What is your position in the construction project?	□ Engineer □ Supervisor □ Asst. Manager □ Manager □ CEO □ Other……………
Q14	How long you have been working in construction industry?	□ 0-1 year □ 1-3 years □ 3-5 years □ 5-10 years □ More than 10 years
Q15	Do your construction project applying 3D printing technology?	□ Yes □ No

Section 2: If you chose Yes in Q15 of Section 1, please answer questions Q16 to Q19 in this section. If you chose No in Q15 of Section 1, please answer questions Q20 to Q23.

No.	Question	Answer
Q16	What type of 3D-printing technology you use in your construction site?	………………………………. (please specify)
Q17	Is it a good investment for 3D printing technology?	☐ Yes ☐ No
Q18	Does 3D printing technology improve your construction project performance?	☐ Yes ☐ No
Q19	Do you need to extend 3D printing technology in other construction sites or other phases?	☐ Yes ☐ No
Q20	Why do you not use 3D printing technology in your construction site?	……………………………….. (please specify)
Q21	Do you have staff who know well in 3D printing technology?	☐ Yes ☐ No
Q22	Are investment and maintenance costs significant in using 3D printing on construction sites?	☐ Yes ☐ No
Q23	What is the level of your construction site performance? (In general).	☐ High ☐ Middle ☐ Low

Section 3: Please read the statements carefully and then select the score about 3D printing in construction industry based on your opinion.

No.	Statement	Scale of important				
		1: strongly disagree	2: disagree	3: neutral	4: agree	5: strongly agree
Relative advantages						
Q24	3D printing can reduce construction time.					
Q25	3D printing can improve material usage.					
Q26	3D printing can reduce construction cost.					
Q27	3D printing can reduce manpower in construction projects.					
Q28	3D printing can construction quality problem.					
Complexity						
Q29	3D printing application is simple.					
Q30	Digital construction process is simple.					
Q31	Computer-aided design process in construction industry is simple.					
Q32	Using and maintaining 3D printer is simple.					

No.	Statement	Scale of important				
		1: strongly disagree	2: disagree	3: neutral	4: agree	5: strongly agree
Trialability						
Q33	3D printing yields acceptable tolerances.					
Q34	The properties of 3D printing materials are predictable.					
Q35	3D printing products are still good in the long term.					
Compatibility						
Q36	3D printing can match with conventional construction.					
Q37	3D printers can make most design elements.					
Q38	3D printing is flexible enough for different construction needs.					
Absorptive capacity						
Q39	3D printing needs the knowledge, skills, and expertise of workers.					
Q40	Most of the workers have a good attitude toward 3D printing.					

No.	Statement	Scale of important				
		1: strongly disagree	2: disagree	3: neutral	4: agree	5: strongly agree
Q41	Extensive cooperation with other companies or research institutes is required.					
External pressure						
Q42	Lack of knowledge about 3D printing in construction.					
Q43	Lack of skilled workers for using 3D printing.					
Q44	Lack of 3D printing suppliers who are trustable.					
Uncertainty						
Q45	3D printing technology is still in the developing phase.					
Q46	There is a side effect in using 3D printing in the construction industry.					
Q47	There is a skeptical concern about the environmental impacts of 3D printing.					

No.	Statement	Scale of important				
		1: strongly disagree	2: disagree	3: neutral	4: agree	5: strongly agree
Supply-side benefits						
Q48	Precast and assembly activities are reduced.					
Q49	3D printing simplifies the construction processes.					
Q50	3D printing reduces the need for transportation.					
Demand-side benefits						
Q51	Quick response to customer demand change is possible.					
Q52	Customized products with plausible prices are possible.					
Q53	The collaboration with customers and suppliers is integrated.					

APPENDIX B

Item-objective Congruence Index

No.	Question	-1	0	+1	Total	IOC	Result
1	What is your gender?	0	1	2	2	0.67	ok
2	How old are you?	0	1	2	2	0.67	ok
3	What is your education level?	0	0	3	3	1.00	ok
4	What is your job position?	0	0	3	3	1.00	ok
5	How much your salary?	0	0	3	3	1.00	ok
6	How long you have been working? (Include previous jobs)	0	1	2	2	0.67	ok
7	What is your education major?	0	1	2	2	0.67	ok
8	What are working at?	0	0	3	3	1.00	ok
9	Do your construction project is in Kunming?	0	0	3	3	1.00	ok
10	How big is your construction project?	0	1	2	2	0.67	ok
11	How many employees in your construction site?	0	0	3	3	1.00	ok
12	Is your construction project state-owned?	0	1	2	2	0.67	ok
13	What is your position in the construction project?	0	0	3	3	1.00	ok
14	How long you have been working in construction industry?	0	0	3	3	1.00	ok
15	Do your construction project applying 3D printing technology?	0	0	3	3	1.00	ok
16	What type of 3D-printing technology you use in your construction site?	0	0	3	3	1.00	ok
17	Is it a good investment for 3D printing technology?	0	0	3	3	1.00	ok

No.	Question	-1	0	+1	Total	IOC	Result
18	Does 3D printing technology improve your construction project performance?	0	0	3	3	1.00	ok
19	Do you need to extend 3D printing technology in other construction sites or other phases?	0	0	3	3	1.00	ok
20	Why do you not use 3D printing technology in your construction site?	0	0	3	3	1.00	ok
21	Do you have staff who know well in 3D printing technology?	0	0	3	3	1.00	ok
22	Are investment and maintenance costs significant in using 3D printing on construction sites?	0	0	3	3	1.00	ok
23	What is the level of your construction site performance? (In general).	0	0	3	3	1.00	ok
24	3D printing can reduce construction time.	0	0	3	3	1.00	ok
25	3D printing can improve material usage.	0	0	3	3	1.00	ok
26	3D printing can reduce construction cost.	0	0	3	3	1.00	ok
27	3D printing can reduce manpower in construction projects.	0	0	3	3	1.00	ok
28	3D printing can construction quality problem.	0	0	3	3	1.00	ok
29	3D printing application is simple.	0	0	3	3	1.00	ok

No.	Question	-1	0	+1	Total	IOC	Result
30	Digital construction process is simple.	0	0	3	3	1.00	ok
31	Computer-aided design process in construction industry is simple.	0	0	3	3	1.00	ok
32	Using and maintaining 3D printer is simple.	0	0	3	3	1.00	ok
33	3D printing yields acceptable tolerances.	0	0	3	3	1.00	ok
34	The properties of 3D printing materials are predictable.	0	0	3	3	1.00	ok
35	3D printing products are still good in the long term.	0	0	3	3	1.00	ok
36	3D printing can match with conventional construction.	0	0	3	3	1.00	ok
37	3D printers can make most design elements.	0	0	3	3	1.00	ok
38	3D printing is flexible enough for different construction needs.	0	0	3	3	1.00	ok
39	3D printing needs the knowledge, skills, and expertise of workers.	0	0	3	3	1.00	ok
40	Most of the workers have a good attitude toward 3D printing.	0	0	3	3	1.00	ok
41	Extensive cooperation with other companies or research institutes is required.	0	0	3	3	1.00	ok
42	Lack of knowledge about 3D printing in construction.	0	0	3	3	1.00	ok
43	Lack of skilled workers for using	0	0	3	3	1.00	ok

No.	Question	-1	0	+1	Total	IOC	Result
	3D printing.						
44	Lack of 3D printing suppliers who are trustable.	0	0	3	3	1.00	ok
45	3D printing technology is still in the developing phase.	0	0	3	3	1.00	ok
46	There is a side effect in using 3D printing in the construction industry.	0	0	3	3	1.00	ok
47	There is a skeptical concern about the environmental impacts of 3D printing.	0	0	3	3	1.00	ok
48	Precast and assembly activities are reduced.	0	0	3	3	1.00	ok
49	3D printing simplifies the construction processes.	0	0	3	3	1.00	ok
50	3D printing reduces the need for transportation.	0	0	3	3	1.00	ok
51	Quick response to customer demand change is possible.	0	0	3	3	1.00	ok
52	Customized products with plausible prices are possible.	0	0	3	3	1.00	ok
53	The collaboration with customers and suppliers is integrated.	0	0	3	3	1.00	ok

VITA

NAME	Zhikang ZHOU