

**THE APPLICATION OF DIGITAL MEDIA IN
ARCHITECTURAL DESIGN AND CONSTRUCTION: AN
ANALYSIS OF DIFFUSION OF INNOVATION**

BY

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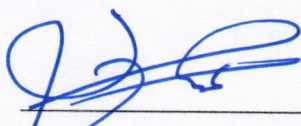
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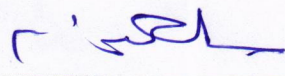
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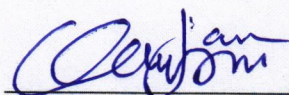
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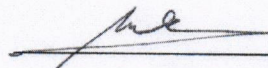
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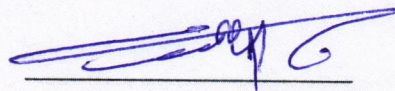
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Greetings to all friends, family, mentors and knowledge seekers interested.

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Throughout the brightest and darkest of days, I humbly thank Allah for the patience and blessings bestowed upon me.

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ABSTRACT

Full Name : [Saud Khalid Saud Abu Mutawe]
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The Saudi Arabian architecture and building production industry is suffering from lack of adoption of new technologies despite the kingdom's efforts in investing in new innovations. Despite contributing 10.95% of the total GDP of non-oil producing sectors, the field's productivity is considered far below "internationally accepted levels". Acknowledging that digital media can help rectify this multi-dimensional issue, this study assesses the usage of digital media technologies throughout the architectural design process in Saudi Arabia. The study adopts a multi-method approach, using a literature review, questionnaire surveys, and interviews for data acquisition. 116 practitioners with local experience participated in the study, while 5 semi-structured interviews were conducted with professionals. Highlights of the findings were that 2D + 3D CAD and building information modeling were the most prominent digital media technologies, with AutoCAD, ArchiCAD and Revit being the most used software packages; Parametric design and big data were the least utilized technologies. These findings were further detailed in relation to the design process phases. The field expressed positive readiness for digital media adoption, but negative sentiments from employees were identified. Additionally, readiness was found to be independent from usage patterns and extents of usage. Finally, financial limitations and lack of technical skills were the major barriers to digital media adoption, while market competitiveness was the leading benefit.

ملخص الرسالة

الاسم الكامل: سعود خالد سعود أبو مطاوع

عنوان الرسالة: تطبيق الوسائط الرقمية في التصميم المعماري والبناء: تحليل انتشار الابتكار

التخصص: العمارة

تاريخ الدرجة العلمية: 2 يونيو

يعاني مجال الهندسة المعمارية وإنتاج البناء في المملكة العربية السعودية من عدم اعتماد الوسائط الرقمية الجديدة على الرغم من جهود المملكة في الاستثمار في الابتكارات. وعلى الرغم من مساهمتها بنسبة 10.95% من إجمالي الناتج المحلي للقطاعات الغير النفطية، إلا أن إنتاجية المجال تعتبر أقل بكثير من "المستويات المقبولة دولياً". وإدراكاً لأن الوسائط الرقمية يمكن أن تساعد في تصحيح هذه المشكلة المتعددة الأبعاد، تقوم هذه الدراسة بتقييم استخدام تقنيات الوسائط الرقمية في جميع أنحاء عملية التصميم المعماري في المملكة العربية السعودية. تتبنى الدراسة منهجاً متعدد الأساليب، وذلك باستخدام مراجعة الأدبيات، والاستبيانات، والمقابلات للحصول على البيانات. شارك في الدراسة 116 شخص من ذوي الخبرة المحلية، بينما تم إجراء 5 مقابلات شبه منظمة مع خبراء. من أبرز النتائج أن برامج التصميم بمساعدة الكمبيوتر (2D + 3D CAD) ونمذجة معلومات البناء (BIM) كانت من أبرز تقنيات الوسائط الرقمية، وكانت برامج AutoCAD و ArchiCAD و Revit هي أكثر حزم البرامج استخداماً؛ كان التصميم البارامترية والبيانات الضخمة من التقنيات الأقل استخداماً. تم تفصيل هذه النتائج بشكل أكبر فيما يتعلق بمراحل عملية التصميم. أعرب السوق السعودي عن استعداد إيجابي لاعتماد وسائل الإعلام الرقمية، ولكن تم إيجاد مشاعر سلبية من الموظفين تجاههم. بالإضافة إلى ذلك، وجد أن الاستعداد مستقل عن أنماط الاستخدام ونطاق الاستخدام. وأخيراً، كانت القيود المالية والافتقار إلى المهارات التقنية من العوائق الرئيسية أمام اعتماد الوسائط الرقمية، في حين كانت القدرة التنافسية في السوق هي الدافع الرئيسي.

CHAPTER 1

Introduction

This study aims to assess the usage of digital media technologies in the architecture and building production sector in Saudi Arabia. In this study, digital media refers to all computer-based applications, software and tools that are adopted and used in architecture and building production. As such, the study examines the use of digital media to support the range of architectural design activities in addition to related activities that translate design into a constructable project. This includes design and other supportive activities such as pre-design analysis, design documentation and working drawings, communication, simulations, and design assessment activities that are not considered part of the scope of the conventional architectural design process by some professionals.

Nowadays, architecture and building production processes are highly reliant on the usage of digital media to improve efficiency, speed, and the quality of the created design products (Knippers Et al., 2021; Penttilä, 2006). These benefits directly affect the design process including all the supportive activities that generally accompany it. Hence, this study will examine the phenomenon within the context of the Saudi Arabian building industry using a multi-method approach that includes a literature review, questionnaire survey and semi-structured interviews.

Using the theories relating to the adoption of new technologies as a base (mainly the IT barometer and the Diffusion of Innovation), the aim of this study is to characterize and determine the level of adoption of digital media in the Saudi architecture and building production field, while assessing the extent of the diffusion of digital media within the architectural design process alongside all its supportive activities. This study focuses both on technologies and software packages to allow for micro and macro levels of investigation.

The building and construction sector represent a major part of the Saudi economy. In 2022, the building and construction sector contribution to the gross domestic product (GDP) was about 4.62% which accumulated for about 10.95% of the contribution of the non-oil producing sectors to the total GDP (Annual National Accounts Publication, 2022). In the same year, the sector employed about 2.54 million people, accounting for 15.96% of the total labor force in the Kingdom. The value of capital assets of the building and construction sector in 2022 was SR192.2 billion, up from about SR169.9 billion in 2021, reflecting an average annual growth rate of 13.1%.

As such, the Saudi Arabian architecture and building production sector comprises the largest market in the whole of the Middle East with multi-billion-dollar projects underway and many more in the planning stage by both the public and private sectors (JLL, 2022). However, the industry productivity is far lower than the “internationally accepted level”, as stated in the Kingdom’s Vision 2030 (also known as the eleventh development plan) and its predecessors, the Tenth (2015-2019) and Ninth (2010-2014) Development Plans (General Authority of Statistics, 2010-2019). The Ninth Development plan suggests expanding the investment in advanced high-tech equipment and tools to improve the

productivity and competitiveness of the sector. The Ninth Development Plan states that “technological development of the sector is a prerequisite for providing Saudis with rewarding-wage job opportunities.” While the tenth development plan focused on the preparation of infrastructure for future development, Vision 2030 refocuses on the adoption and investment in new technologies in all relevant sectors. Therefore, enhancing the efficiency of the building and construction sector through adopting advanced digital media technologies, and through education and training, is very crucial. The Ninth Development Plan has recognized this need by highlighting that its future development strategy vision is to create “a developed, efficient building and construction sector led by highly competent contracting companies with high-level technical capabilities, spread in all regions of the Kingdom.” Additionally, Vision 2030 adopts this sentiment by committing 2.5% of its annual GDP to adopting and developing new technologies and innovations.

Although Saudi Arabia has invested heavily in advanced information and communication technology (ICT) in the past decade or so (Rogozhin, 2021; Gheraia Et al., 2021), the building and construction industry seems to be very slow in adopting and employing these technologies in their operations. Literature points out that the building and construction industry is a fragmented, project-based industry (Mellado Et al., 2020; Fulford Et al., 2014). A typical project involves the participation of different stakeholders such as the owner, architect, structural engineer, building systems engineers, surveyors and technicians, developer, construction contractor, sub-contractors, suppliers, and other specialists. Literature indicates by enhancing the flow of information across the various phases of a building/construction project and the various disciplines and stakeholders involved in a project, digital media plays a major role in improving the efficiency and

productivity of the building and construction sector while elevating the quality of its outputs (Nawi Et al., 2014). Literature shows that the “integrated building and construction process”, which is facilitated using advanced digital media, represents a corner stone to overcome the limitations of the fragmented business model of the industry and to further improve the efficiency and productivity of the industry (Owen Et al., 2010).

Research points out that during the past three decades, the use of digital media has allowed all industry sectors to achieve notable quality and productivity gains. The advantages and benefits of using digital media in the building and construction industry in addition to the types of technologies and innovations used have been established by several studies (Chen Et al., 2022), while few studies have examined the performance of the building and construction industry itself in this regard. Primary research on the usage of digital media in the Saudi building and construction industry shows that there is little research on the topic from the perspective of readiness of the market. Examples of aspects covered by other studies include lean construction practices usage (Sarhan Et al., 2018), BIM implementation and reliance (Al-Hammadi Et al., 2020), IT and remote communication technologies and solutions (Sidawi, 2012). Therefore, there is an urgent need to examine and analyze the degree of digital media adoption and use in the Saudi architecture and building production field to assess the foundations for future developments in line with the intended growth of the field.

1.1 Problem Statement

In the architecture and building production sector, advanced digital media technologies are considered to be a source of competitive advantage for firms and organizations that prioritize the development and implementation of new technologies and innovations to improve performance and efficiency (Sexton & Barrett, 2005; Ling ,2003; Seaden 2003). Hence, to improve performance and increase productivity and quality of work, the level of adoption and diffusion of new technologies and innovation needs to be assessed in relation to the intended contexts. Extensive research efforts have been conducted to identify the factors that affect innovativeness (Bossink, 2004) and the implementation of innovations within a firm/organization (Peansupap & Walker, 2005); which requires both bottoms-up and top-down efforts for the proper diffusion of said innovations (Koskela & Vrijhoef, 2001; Winch, 1998)

Although the Kingdom has invested heavily in the information technology and digital media technology sector, the adoption and use of advanced digital media in the architecture and building production industry is not as much. Saudi Arabia continues to focus on early investment in digital media advancements, where 2.5% of the annual GDP is set to focus on research, development, and innovation by the year 2040, where the four areas of investment are Health and Wellness, Sustainable Environment and Supply of Essential Needs, Energy and Industrial Leadership, and Economies of the Future (The Embassy of the Kingdom of Saudi Arabia, 2022). Although economies of the future include mega architectural projects, the investment is towards the procurement and construction of the

projects themselves instead of developing technologies, further highlighting the inadequacy of digital media focus within the architecture and building production sector.

Literature indicates a lack of research on the diffusion of digital media technology in the Saudi architecture and building production sector, in addition to the lack of official statistics on the usage of digital media in the Saudi Arabian architecture and building production field. Slightly similar studies exist, one of which was done in 2003 (Al-Gahtani, 2003) which is a very highly cited publication but is very general, and another was even before that in 1997 (Shash, 1997) and the findings were simplistic and had an administrative focus. As such, the current status of the use of digital media and information technology in the firms of the architectural and building production sector in the Kingdom is not known. The proposed research study aims to fill this gap by providing in-depth analysis and assessment of the adoption and use of digital media in the Saudi Arabian architecture and building sector in terms of the types of digital media used, the actual level of usage, integration into the design and work process, factors that hinder and/or drive adopting advanced digital media in the industry, actual advantages and disadvantages experienced by the industry, the current level of innovation diffusion readiness, in addition to relating these findings to current practices in some of the developed countries.

Hence, major research questions in this study include:

- What types of digital media technologies are being adopted?
- What are the usage patterns of digital media across different design activities?
- How deep is the diffusion of digital media?

- What is the level of digital media adoption?
- What are the advantages and disadvantages of digital media adoption?
- What is the level of automation implemented during the design process?
- How ready is the industry for the adoption of advanced digital media technologies?

1.2 Research Objectives

The research aims to examine and assess the level of adoption and use of digital media (i.e. applications, computing resources, and information technology) in the architecture and building production in the Kingdom of Saudi Arabia, its impact on work processes in the field, as well as the benefits and barriers of adoption. Hence, the research aims to achieve the following objectives:

1. Identify **types of digital media technologies** that are in use in the Saudi architecture and building industry.
2. Identify **usage patterns of digital media technologies** across different phases of the architecture design and building production process. This includes identifying types of design activities and work processes supported by the existing digital media resources and the extent of such support.
3. Identify and assess the **level of digital media diffusion, level of adoption, and the benefits and barriers** of adoption in the Saudi architecture and building sector.

4. Assess the **level of automation** in design activities and related work processes in the architecture and building industry and its impact on the industry's productivity.
5. Identify and assess the **readiness of the Saudi architecture and building production industry** for (advanced) digital media technologies to maintain completeness and currency with information technology developments

1.3 Study significance

Utilizing innovative technologies to integrate teams, improve efficiency and productivity, and enhance products and processes, is becoming a major characteristic of the architecture and building production sector worldwide (Chen Et al., 2022). Although, the Kingdom has invested heavily in the information technology and digital media technology sector, the building and construction industry seems to be way behind in adopting these developments (The Embassy of the Kingdom of Saudi Arabia, 2022).

As the use of digital media is crucial for adoption, the Kingdom ensured to invest in adopting and developing new technologies across various sectors. Unfortunately, those plans focus on the architecture and building production field explicitly through projects rather than technologies, leaving the responsibility to the whims of the projects' stakeholders. Hence, to showcase the opportunities for alignment between digital media adoption and the goals declared by the development plans, this study responds to those needs by providing information on the current state of the industry while addressing all the possible benefits of digital media.

By assessing the level of adoption and use of digital media and related technologies in Saudi Arabia, the study can highlight prominent issues in the professional field and provide recommendations to overcome them. Digital media technologies aim to improve efficiency, increase the speed of processes, improve accuracy, and reduce the redundancy of work being performed by architects, designers, and engineers. This creates more opportunities for creative exploration within the architecture and building production design process without sacrificing the quality of tasks performed.

By highlighting the potentials of digital media technologies in the professional field of Saudi Arabia, stakeholders are encouraged to invest time and money into their research and development as it directly translates to an improvement in their enterprise's work. Additionally, this study will provide a clear position of Saudi Arabia when compared to different countries in terms of digital media adoption. This translates into discovering unexplored opportunities for adoption from other contexts.

In general, the research outcome will be valuable for practicing professionals involved in the architecture and the building production field (i.e. architects, contractors, engineers), decision makers in the public and private sectors, non-governmental organizations and professional bodies concerned in developing the sector, and for governmental agencies and ministries interested in strengthening and developing the capacity of the sector such as the Ministry of Municipal and Rural Affairs and the Ministry of Economy & Planning. Additionally, the research results will be useful for researchers, academicians, training and service providers, and other stakeholders involved in planning for adopting digital media products, applications, and services appropriate for the Kingdom.

1.4 Scope and limitations of Study

The study examines the level of diffusion of digital media within the Saudi Arabian architecture and building production sector, and the impact of this adoption on working processes and the quality of work produced. The study has several inherent as well as self-imposed limitations that define the scope of the study. The main limitations of the study are as follows:

1. The study is limited to architectural design activities within Saudi Arabia, in addition to design documentation and supportive design activities leading to the construction phase of the building life cycle.
2. Only practicing architecture and building construction firms will be examined. The focus is on architects and other professionals involved in actual design activities rather than construction.
3. The focus will be on enterprise-level aspects; external factors (personal, political, unforeseen circumstances) beyond the enterprise will not be considered.
4. The study is a cross-sectional exploration that examines a wide range of digital media applications without focusing on specific digital media technologies.

1.5 Thesis structure

The remainder of the thesis is organized as follows:

- Chapter 2 (The literature review) provides an extensive review of relevant existing research. It reviews digital media technologies and applications currently available and in use, design and building activities within the

architectural design process, information flow across projects, diffusion of innovation as a theory and its application in the architecture and building production sector, and digital media applications in the Kingdom of Saudi Arabia.

- Chapter 3 (The methodology) presents the methodological framework followed through the study. It describes the methods used for data collection (i.e. the questionnaire and interview) and the framework used to analyze the data.
- Chapter 4 (Data analysis and Results) presents the results and findings of the analysis of the data collected.
- Finally, the discussion and conclusions, chapter 5, discusses and reflects on the study's results and findings, and proposes supported conclusion based on the results of the data analysis. Future research directions and some recommendations for the future adoption of digital media in the architecture and building production field in Saudi Arabia are also provided. Figure 1 shows a summary of the thesis' structure along with the main topics covered in each section.

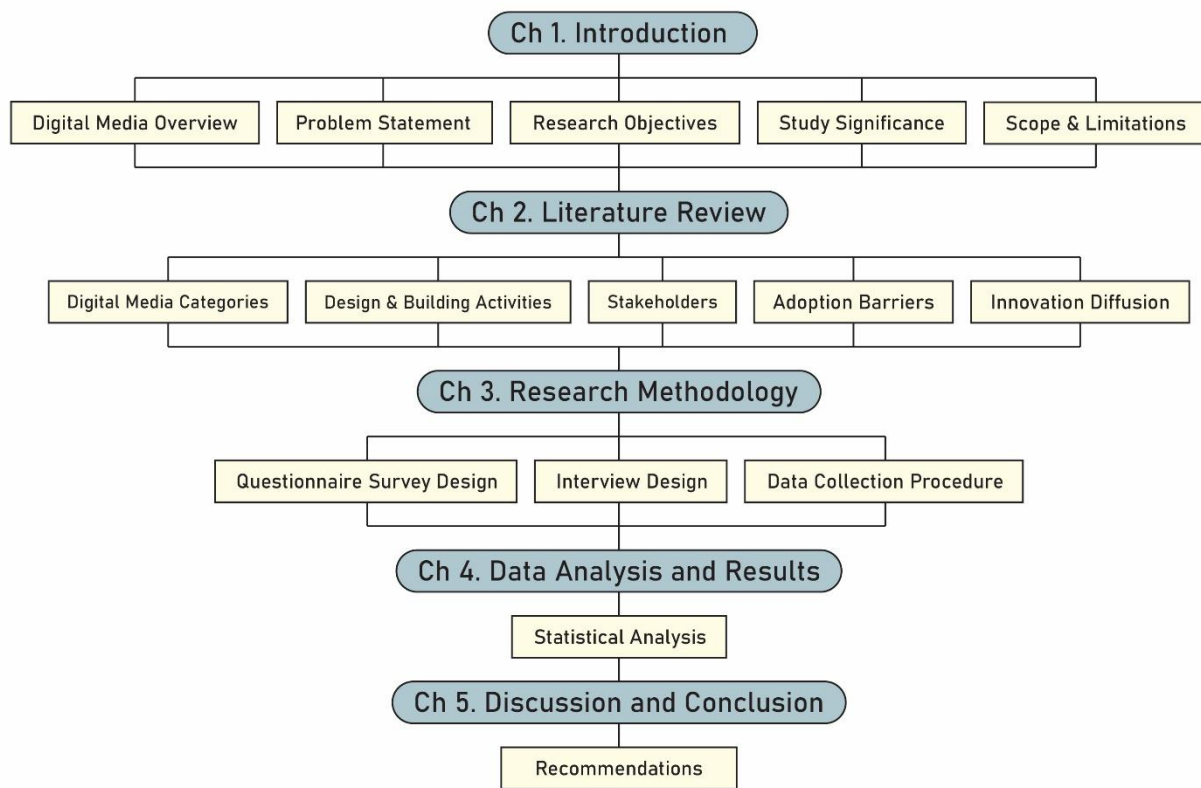


Figure 1: Thesis Structure

CHAPTER 2

Literature Review

This chapter reviews existing research studies pertinent to the digital media use in professional practice in architecture and related areas. The review provides essential information to develop the research study framework including theoretical and methodological aspects. The review is organized into the following main sections: architectural design and related building production activities, advanced digital media applications in architecture, information flow across projects, adoption and diffusion of digital media in architecture, and digital media applications in KSA.

2.1 Architectural Design and Building Production Activities

Architecture design activities have been examined in a wide range of theoretical and empirical studies. Research on design methods and design processes began in the early 1960s and has continued to the present under the name design thinking. This section reviews relevant literature in the design methodology area and presents relevant findings. This section covers the process of producing an architectural design that can be transformed into a real architectural product; architectural products include all types of buildings, open spaces, landscape projects, and urban level planning and design projects. In contrast to architectural design, the term “building production activities” can be ambiguous to interpretation. It has been defined in various ways in literature where some focused on the managerial work during the construction phase (Barkalov Et al., 2017) while others expanded the scope to include the documentation and preparatory systematic work done

prior to the actual construction process (Osuizugbo Et al., 2020). Other studies expanded the scope even further to include the preparatory work needed for digital manufacturing activities (Breen Et al., 2005). To avoid any misconceptions, the definition used in this study defines building production activities as all activities that aid in the transformation of a digital architectural design into a real design product excluding the actual procurement/manufacturing process.

The architectural design process is generally viewed as the process of producing an architectural design product while complying with a set of rules enforced by the context and the nature of the project itself. However, the phases of the architectural design process are not intransigent as they differ based on the individuals responsible for the project. The architectural design process mainly involves analysis-reliant synthesis where multiple factors (physical, cultural, contextual, environmental, etc.) are relied upon to guide the production, development, and optimization of the architectural design product (Zhuang Et al., 2017; Uzunoğlu Et al., 2011). Regardless of the intricacies of what is done within the design process, the desired objectives must be clearly defined, followed by the production of alternate solutions to design problems, and finally, evaluating the performance of said solutions in relation to the initially defined objectives (Carrara Et al., 1994). Additionally, other studies include actions like communications and decision-making in the architectural design process (Moum, 2006), which are seen as intrinsic parts of a successful design process although they aren't technically design phases.

Hence, the following phases were established for the study in accordance with the notions of literature while also providing a comprehensively expansive perspective. Additionally, they were chosen to be direct tangible design activities while communications are

addressed within the phases themselves in addition to further chapters in the context of technologies.

2.1.1 Predesign Phase

The predesign phase in the architectural design process is one that builds the foundation on which the design product will be based on. No actual design is done in the predesign phase, as the phase is only concerned with properly realizing a project's vision and general requirements; this includes both aesthetic and functional aspects. Hershberger provided an exclusively design based perspective, where their definition of predesign focuses on effectively programming for a project using diagrams, sketches, basic drawings, and reference images that help convey the general favored outcome of the entire design project (Hershberger, 1999). Programming in this context refers to preliminary representations of different aspects of the architectural project whose objective is to communicate the different perspectives of the project as clearly as possible while negating the actual design product (Hershberger, 1999). It is important to note that the majority of the predesign phase is done based on generalizations and unconstrained ideation; this is due to the exploratory nature of the phase.

With the developments of digital media, the scope of the predesign phase was expanded to include more technical aspects that help in solidifying the foundation laid by the phase for the rest of the design process. Lee and his research team summarized these aspects into three categories: predictive analyses of the costs accompanying the project, energy and resource demands, and massing calculations based on the expected number of users (Lee Et al., 2016).

Finally, Smith stated that recursiveness is the cornerstone of the predesign phase, whose quality and effectiveness are determined by input from various sources; hence they suggested that key individuals and stakeholders can be introduced to the architectural design process early during the predesign phase to collectively establish projects' parameters and performance requirements in an efficient manner (Smith Et al., 2004).

2.1.2 Preliminary Design Analysis

Preliminary design analysis is the last design phase which does not include any actual architectural design within it. According to early research done by Finn, this phase is a direct continuation of the preparatory work done in the predesign phase; preliminary design analysis is mainly concerned with comparing alternative approaches adopted from the predesign phase and deciding on the most appropriate ones to continue working on. Finn established that these approaches may be direct guidelines for the remainder of the architectural design process or recommendations for further analyses based on findings at future points (Finn Et al., 1992). Similar to the predesign phase, Nakakawa shared the same sentiment with Smith regarding the importance of inclusiveness in the decision-making process, which is done by jointly undertaking it with key individuals and stakeholders (Nakakawa Et al., 2009).

2.1.3 Conceptual and Schematic Design

Though they are two different architectural design phases, conceptual and schematic designs are extremely similar and are usually used interchangeably in literature despite their differences. According to Rusevych, the conceptual design phase is the most creative phase within the entirety of the architectural design process, where the focus is purely on ideas regardless of their applicability (Rusevych Et al., 2021). A similar sentiment was

proposed by Pollalis, where they defined the conceptual design phase as a relatively unrestricted exploration of ideas and concepts in design, where the only “restrictions” are the design guidelines established through preliminary analysis and the predesign phase (Pollalis, 1994). According to Çıkış, and in accordance with the phase’s unrestricted nature, communication and representation of ideas in the conceptual design phase can be done through the systematic usage of all means that the designers deem most appropriate for conveying their ideas; this can be through language, diagrams, drawings, or any other media (Çıkış Et al., 2010). Those new ideas are reliant on previously acquired knowledge in combination with the creativity of the individual to create new unique solutions within the given confines and requirements, where Pena highlighted that this process is substantially improved using digital media technologies like artificial intelligence (Pena Et al., 2021).

Finally, it is worth mentioning that the differentiating factor between conceptual and schematic design is that schematic designs are more grounded in reality. They represent actual architectural elements, zones, and structures while still exploring different approaches to a project. It is an evolution of conceptual design without being completely rigidified by the constraints of architectural projects. This rationale was well established by Liu, who stated that the schematic design phase allows for a realistic actualization of design criteria and goals while comparing different developed conceptual approaches (Liu, 1991). Unlike the conceptual design phase, the schematic design phase has some introduced rigidity as it is closer to realistic architectural product rather than an abstract concept. This is why Suryani and Salgueiro identified that potential for digital media technologies to improve the effectiveness of the phase. Both namely acknowledged BIM-

based applications, as they closely resonate with the semi-rigid nature of schematic designs and their need to briefly assess multiple design alternatives simultaneously in quick succession while conducting comparisons (Suryani Et al., 2019; Salgueiro Et al., 2015). This highlights the difference between conceptual and schematic design phases; as was stated earlier that Pena recognized artificial intelligence and its creative capabilities as most suited to support the conceptual design phase, which contrasts the requirements and consequently digital media technologies utilized in the schematic design phase.

2.1.4 Design Development

Design development refers to reiterating and reevaluating different architectural design products to ensure that the most viable one is chosen. Design development is a very time-consuming phase as every single aspect of the architectural design product is being reiteratively optimized on its own, then that optimization is viewed in the context of the entire project. Additionally, multiple design activities in different areas of the project (structures, planning, systems, etc.) are all done simultaneously during this phase, which is why it takes a lot of time.

The design development phase is where most of the architectural designing happens, which is why great emphasis is placed on management during this phase. Although each design activity has its own intricacies, great emphasis is placed on efficient ordering of these activities to ensure no overlapping of codependent activities together which causes the entire design process to freeze. There are two approaches to efficient design development according to literature, optimized singular activities and optimized scheduling.

Optimized singular activities is an approach coined by Devendorf, where each design activity is optimized in isolation, resulting in improvements in various areas that produce

a compounding effect on the whole design development phase; As each subsequent individual design activity will theoretically take less alternatives to reach an optimal solution, less time will be needed for the overall design to be produced (Devendorf Et al., 2011). The main issue with this approach is that it goes completely against numerous studies emphasizing the importance of communication by disregarding the bigger picture of the project and losing a lot of collaborative opportunities between different disciplines that may result in unique interdisciplinary solutions that aren't possible when isolating design activities. Alizadehsalehi's findings completely disagree with the core principals of optimizing singular activities, as this approach gives minimal importance to the integrated design process which has been proven to considerably improve the efficiency of the architectural design process throughout all its phases (Alizadehsalehi Et al., 2019).

Optimized scheduling is a purely managerial approach that was introduced by Wang. It refers to the simple act of distributing different design activities into a time efficient manner that prevents any overlapping between activities that sequentially rely on each other (Wang Et al., 2016). This approach doesn't take into consideration how each individual design activity is carried out. Finally, it is worth noting that both approaches of efficient design development eliminate a portion of communications that occur during the design development phase. Alizadehsalehi suggested that both approaches are needlessly extreme and can be replaced by simply adopting an integrated design process approach, which encompasses the advantages of both approaches while negating their shortcomings (Alizadehsalehi Et al., 2019).

Finally, it is worth mentioning graphical thinking, a well-established problem-solving approach that combines the design development phase with the presentation and

documentation phase. According to Gillieson, it relies on different types of graphical presentation methods as the driving factors of design development, which relies on a constant recursion of generation, synthesis, evaluation, and production of future-conscious design solution (Gillieson Et al., 2018). Gillieson highlights that this approach is extremely malleable and consists of a set of principles that can be easily introduced to any architectural design process, which in return preserves the design process for future reference; This can be seen in historic architectural archives where graphic thinking's principals were adopted to preserve architectural design processes throughout the years.

2.1.5 Presentation

This is the phase that introduces the design product to individuals who weren't involved in the architectural design process. According to Oshida, this can be accomplished using sketches, diagrams, figures, renders, videos animations, or any other appropriate method (Oshida, 2011). Presentation can be done for the final completed design product, or for different phases of completion to show the design's development incrementally. It is worth noting that presentation is the first phase that introduces the design to external parties, but it is also done recurrently on an internal level throughout the design process for communication purposes. There are two types of presentations:

- Workflow Presentation
- Design Product Presentation

Balazs defined workflow presentation as using presentation on an internal level to help clearly communicate design developments in a more approachable manner for different individuals involved in the architectural design process. Boeykens agreed with this notion,

indicating that the incorporation of the presentation phase throughout the entirety of the architectural design process improves workflow when progressing through different design activities, which in turn enhances the overall quality of the design process (Boeykens Et al., 2006; Balazs Et al., 1997).

On the other hand, Pejic stated that design product presentation is concerned with presenting any or all parts of the architectural product to individuals not involved in the architectural design process. These can be stakeholders, clients, regulatory bodies, and so on. Pejic also emphasized that with the growing complexity of projects, digital media utilization is essential for easier and more intuitive design product presentation processes (Pejic Et al., 2017). This sentiment is shared with Hadiyatna, as they stated that the use of digital media is crucial for effective communication between architects and individuals foreign to the architectural design process (Hadiyatna Et al., 2020) as it simplifies complex concepts and make their understanding a much more accessible feat for nonprofessional people.

2.1.6 Documentation

Documentation of an architectural product is a continuous process that starts with the beginning of any project and ends with the end of the constructed architectural product's lifetime. This phase is involved with relevant data storage throughout the project, in addition to ensuring the availability of said data whenever required. Douglas highlighted the importance of efficient documentation, stating that it's crucial for the successful fulfilment of project objectives as it is responsible for directly linking requirements to the implemented design decisions and ensuring that such a linkage is established by guiding the architectural design process accordingly (Douglas, 2010). This is consistent with

Boake's earlier findings, where they identified its major role in the decision-making process, as proper documentation leads to improved communications in addition to having a clearer guiding vision for the project (Boake, 2008).

Documentation shares its preservatory nature with Gillieson's graphic thinking approach, which was discussed earlier, where all decisions made throughout the architectural design process are stored with their reasoning (Douglas, 2010). Duddukuri further highlighted the importance of this preservatory nature, allowing the documentation of different architectural projects to be used as a knowledge base for future reference in architectural endeavors (Duddukuri Et al., 2005).

To further emphasize the importance of the documentation phase throughout the architectural design process, efforts have been made to redocument the architectural design process of existing built buildings to capture their details and archive them. Kazman stated that this can be done conventionally using architectural reconstruction, which acts like a reversed architectural design process where the design product is matched with the initial objectives of the project through a systematic approach that uses existing data to aggregate multiple levels of abstraction to obtain documentation that accurately represents the design product (Kazman Et al., 2001). Song highlighted the potential benefits that digital media technologies introduce to architectural reconstruction, specifically the usage of artificial intelligence and machine learning to automate the process by using language processing techniques that analyze all available documents and deduces relationships and details based on found correlation and relationships within the language used throughout (Song Et al., 2018).

Documentation is an umbrella term for all information archiving that happens throughout the architectural design process. However, specific types of documentation are unique design activities on their own as they all individually play major roles in the building production and construction process. These documentation design activities all occur after the entirety of the architectural design process is completed and are as follows:

- Construction Drawings and Specifications
- As-Built Documentation

Construction drawings, also known as construction documentation, are documents produced after the final design drafts are approved; Parts of these documents are also produced procedurally within the construction phase. According to Davis, they are meant to quantify and guide the required activities for the construction process to sufficiently produce the architectural product in the required specifications (Davis, 1997). Banerjee and Maity further elaborated on the nature of these documents, stating that they are highly technical (including dimensional details of all parts of the architectural product) in addition to including important connections and cross-referencing between documents of different parts of the project as they act as comprehensive guides for the entirety of the construction phase (Banerjee Et al, 2017; Maity Et al., 2017). Finally, Robbins established that construction drawings are done in the form of geometric projections (orthographic, axonometric, isometric), plans, sections, elevations, and working drawings (Robbins Et al., 1997).

As-Built documentation refers to undergoing architectural reconstruction of an existing architectural product to produce data similar to the construction drawings, but for the actual

construction instead of the intended design; This is mainly because discrepancies usually exist between the original intended architectural designs and the final construction. Based on Kazman's findings, as-built documentation is mainly done for individual implemented systems within the architectural product. This helps in system reasoning which in turn facilitates redocumentation and future reengineering activities (Kazman Et al., 2002; 2001). Thor and Park stated that as-built documents include architectural drawings (usually using CAD), detailed systems plans (usually using BIM), performance test reports, actual dimensions of spaces, equipment used within systems, and occupational project reports over various periods of time (Thor Et al., 2019; Park Et al., 2017). These findings are similar to Banerjee and Maity's findings regarding construction drawings, but they highlight the stark difference in technical details of each type of documentation, where as-built documents are more comprehensive and better represent the architectural product.

2.1.7 Post-Occupancy Evaluation

Post-occupancy evaluation is a research activity that benchmarks the architectural design product against its design process and the objects set during it. Though not technically an architectural design process phase, it concludes the entire project after a set period after the construction is done, where the data acquired is more important for future projects rather than the one being evaluated. As Liu described it, post-occupancy evaluation is an assessment of an architectural product's success from the perspective of its users, who are the best source of information regarding the architectural product's performance (Liu, 1999). Other definitions share the same sentiment with Liu, like Vásquez-Hernández's which states that the architectural products are assessed after inhabitation to determine their performance and to collect data for reference in future designs (Vásquez-Hernández, 2017).

Hay shared similar sentiments but emphasized the future benefits introduced by this process. He argued that it is done to learn from all the issues that projects face and how they were overcome, which in turn allows for improved performance of future buildings that satisfy the needs of users, stakeholders, and society (Hay Et al., 2018).

In contrast to as-built documentation, post-occupancy evaluation is done through nontechnical methods as it focuses on variable user experiences rather than fixed calculations. As purported by Preiser, the methods used include qualitative methods, like self-reporting or interviews, and quantitative methods like multivariate analysis, observatory analysis of usage, and finally the opinions of experts through judgement (Preiser Et al., 2008). Alvaro expanded on Preiser's methods, highlighting the importance of qualitative methods since post-occupancy evaluation is crucial in assessing internalized sentiments and the psychosocial welfare of users (Alvaro Et al., 2016). This is because such factors can't be properly analyzed at any design phase without having feedback from users experiencing and interacting with the architectural product regularly.

2.1.8 Impact of Digital Media on the Architectural Design Process

The development and adoption of digital media within the architecture and building production design process was the reason for a lot of changes to the design process itself. As stated by McGinley, these include systematic changes which call for a philosophical recontextualization of the design process as a concept and thought process (McGinley, 2014). In conjunction, Ervin's approach states that those systematic changes must focus on retrofitting the established general design process for the adoption of digital media while clearly identifying the general strengths and weaknesses of both analog and digital

approaches, creating a systematic design process which maximizes the utilization of both approaches called a cybernetic design cycle (Ervin, 2016). Ervin's proposed cybernetic design cycle consists of six cyclical phases, which theoretically continuously feed into each other, under two main categories:

- Analog / Manual:
 - Implementation / Construction
 - Inhabitation
 - Perception / Measurement
- Abstract / Digital:
 - Analysis / Needs / Goals
 - Design / Invention
 - Communication / Representation

Other approaches for incorporating digital media into the design process agree with the cybernetic design cycle while having minor differences in the terminologies used and the depth of the definition of phases of the design process. An example can be seen in Lee and Theidel's studies focusing on the manufacturing aspect of the process through case studies, where the general idea of the proposed design proposes are consistent with the cybernetic design cycle but delve into deeper areas based on their field of interest (Lee, 2016; Theidel, 2021).

Other studies, however, considered digital media to be an addition to the architecture and building production design process instead of attempting to rethink the entire process for the incorporation of digital media. The focus here is only on the areas that are relevant to

by the area of the study itself, and not on the whole design process. Rodrigo and Ozdemir's studies introduce completely new phases (Rodrigo Et al., 2018; Ozdemir Et al., 2022) which add to the scope of the design process, while Ming expanded certain areas of the established design process to incorporate their introduced digital media usage (Ming Et al., 2021).

The efforts made to incorporate digital media into the architecture and building production design process are reinforced by digital media's capabilities of retroactively linking the real world into the conventional design process. Sinnamon stated that this linkage helps designers realize their designs in a realistic manner, as real-world sense and physical activities have been shown to improve the overall quality of design products for designers with limited experience (Sinnamon Et al., 2022). Many areas benefit from this linkage, predominantly the manufacturing processes for intricate designs (Agkathidis Et al., 2019), exploring material choice alternatives (Grigoriadis, 2022), comparing and producing detailed design alternatives (Abrishami Et al., 2014), and incorporating human experience into the design process in a qualitative manner (Mussi Et al., 2021). Though the benefits acquired are fascinating, they are all mainly facilitated due to the availability of information.

It is worth noting that the usage of digital media has different impacts on the architectural design process based on the experience of the individuals partaking in it. This can be assessed by examining the effects at introductory levels, where individuals are considered to be novices, and at advanced levels where the individuals concerned with the architectural design have sufficient experience to effectively be capable of carrying out the design process in a conventional manner without any issues.

Novices are all personnel who have very limited experience regarding architecture and building production professional practice. Novices can be young practicing architects, architecture students or architects who still do not have any tangible experience. Past studies focusing on novices share the emphasis on the importance of digital media in the architecture and building production design process, and how it needs to be incorporated at early stages of the professional life cycle. Rivka observed that novices who adopt digital media into their design processes can present their data in multiple ways which improves their presentation capabilities (Rivka, 2008). Additionally, Ting argued that the introduction of these technologies doesn't hinder the creative design process but instead frees the architects from tiring tasks which can be easily automated, giving time to the architect to focus on the creative design process (Ting Et al., 2014).

One of the issues that novices face is the lack of realization of their suggested designs, making a lot of proposals invalid due to integral mistakes which arise due to the designer's lack of contextual imagination. Alatta and Freewan suggested that integrating the creation of virtual environments for design proposals will enhance the designers' spatial perception throughout the entire architectural design process. The main way of accessing these fully immersive virtual environments is by using virtual reality technologies (Alatta & Freewan, 2017). However, Vasconcelos and Sperling argue that digital media can't completely overhaul parts of the architecture and building production design process just yet. This equates to a relationship of coexistence, where the designers continuously alternate between using digital media and traditional representation, using the most beneficial approach (Vasconcelos & Sperling, 2017).

Alalouch led efforts aimed at easing the introduction of digital media to novice and educational contexts using a non-CAD method which was purposely designed to help in this introduction (Alalouch, 2018). While Stavric disagreed with Alalouch's approach, where they adopted a direct digital media centric approach. This was done by conducting practical modelling projects where the entirety of the modelling was done using digital media, namely parametric design, allowing the introduction of digital media through firsthand experience (Stavric Et al., 2016).

The effects of the introduction of digital media into professional architecture and building production field varies based on the architectural design phase it is introduced to. Zafer and Halime argued that it isn't necessary in conceptual design phases, where a more traditional approach tends to be more beneficial because of the easiness of the introduction of quick basic alternative solutions to design problems (Zafer & Halime, 2003). However, Jiangang argued that, based on his practice centered studies, a middle ground can be found which allows the traditional analogue-based conceptual design phase to be used as a starting point for the integration of digital media (Jiangang Et al.,2021). Supporting this notion, Solana noticed quantifiable improvements in certain fields due to the usage of digital media, namely parametric design, to develop traditionally produced initial conceptual designs (Solana Et al., 2017).

Sketching is an obvious point of contention regarding digital media. Here, sketching refers to random design ideas being visually presented in the form of drawings or diagrams, similar to graphic thinking but on a much simpler scale. Heidari observed that designers were more creative and had generally better creative outlooks when using traditional sketching methods, using pen and paper instead of digital media. Additionally, when

comparing digital media technologies to one another, designers were representing their ideas better using two-dimensional sketching software in contrast to their three-dimensional counterparts. It is deduced that traditional sketching is still valuable in the presence of digital media, especially in earlier more erratic architectural design process phases (Heidari Et al., 2019).

The incorporation of digital media into the schematic design phase gave it a lot of added value. This is because reliable data can be produced in the schematic design phase which can be used as a reference for advanced design decisions. These range from comparing the efficiency of design alternatives in early stages (Mattern & König, 2018), creating interactive models where feedback/edits can be directly applied to the main project (Menges Et al., 2012) and even using data from the schematic designs to calculate costs and other technical factors of the projects in relation to different design alternatives (Rad Et al., 2021).

It is worth noting that digital media can replace particular design activities in a set context but can't completely replace a key phase of the traditional architecture and building production design process. Hence, Bhooshan introduced parametric design thinking (PDT) as a complete overhaul of the traditional architecture and building production design process. Having been directly derived from practice, it focuses on a problem-solving approach in architecture (Bhooshan, 2017). PDT isn't the only approach developed which relies on digital media as a replacement for parts or the entirety of the design process. Karan proposed approaches that completely relies the act of optimizing design solutions (output) on digital media, namely parametric design, while keeping the contextual building of the project (input) still be done by designers (Karan Et al., 2021). Hence, the consensus is that

the architectural design process needs human intervention for information and parameter input, whereas digital media can analyze and optimize alternatives in a more efficient and quantitative way.

Finally, it is worth highlighting the effects of digital media on creativity in the professional architecture and building production field. Firstly, Dash stated that the availability of in-depth data due to the adoption of digital media increased the creative potential for architects. He deduced that because they have more comprehensive insights into the project and its details, intricate solutions become plausible and more likely to be adopted (Dash, 2021). Even when disregarding the availability of information, Yu stated that the mere adoption of digital media into the architecture and building production design process results in enhanced creativity from multiple perspectives (Yu Et al., 2018). This sentiment was shared with Schnabel and Iordanova, their reasoning being that the explorative nature of digital media encourages the development and implementation of unexpected design decisions into the final design product, while preventing complexity from being an issue (Schnabel, 2007; Iordanova Et al., 2009).

2.2 Advanced Digital Media Applications in Architecture

This refers to digital media technologies that are focused on adding depth to the design process by including new considerations. These are considerations which weren't possible before digital media and were dependent on preconceived notions or predictions. Ma's research focused on visual human perception of existing spaces and how visually overwhelming a space can be (Ma Et al., 2021), this was done as a continuation to Alatta and Freewan's study of physical spatial perception of designed spaces throughout the architecture and building production design process (Alatta & Freewan, 2017); The

aforementioned studies guided Sinnamon's findings that stated that the disconnect between digital design and reality effects the overall quality and applicability of design products (Sinnamon Et al., 2022). According to Chaszar and Joyce, this reduction in design applicability is due to the extreme experimental freedom provided by digital media technologies (Chaszar & Joyce, 2016). Though Schnabel and Haslop argued against Chaszar and Joyce's sentiments, stating that this experimental freedom is primarily responsible for new innovations in design (Schnabel & Haslop, 2018) which is supported by Abrishami's studies where it was found that digital media facilitated the efficient exploration of new ideas throughout the architecture and building production design process (Abrishami Et al., 2014).

Other approaches of using digital media are to include more considerations to root designs into reality using simulations. Teucher, Kowalewski, and Girot developed technologies simulating natural environmental elements to enable more informed design decisions, which can provide real-time data extraction and analysis (Teucher Et al., 2022; Kowalewski & Girot, 2021), while Ascensão focused on analyzing data from existing digital maps (Ascensão Et al., 2018). Reasonably, supportive studies like Alvear's that focus on the availability of data for simulations accompanied those developments in the usage of simulation technologies (Alvear, 2020). Sędzicki further expanded on Alvear's studies, enabling the automation of purely data-driven decision making (Sędzicki Et al., 2022). This is in line with Walls and Walliss' studies, which states that automation and simulation technologies add important additional perspectives to design optimization and decision making (Walls & Walliss, 2020).

Chiarella and Alvarado focused their work on making physical material considerations possible throughout the architecture and building production design process. This is done by simulating realistic physical properties of materials used in designs in early stages and showing how they act in different design circumstances (Chiarella & Alvarado, 2015). According to Grigoriadis, this is important as projects often include different materials used coextensively or in a conglomerate depending on the wanted properties (Grigoriadis, 2022). Agkathidis' findings state that this relationship carries over to manufacturing, as these considerations streamline the process due to recognizing the physical behavior of materials is known early and designs are done accordingly (Agkathidis Et al., 2019).

Soulikias warned against the overreliance on digital media technologies develop, as it is important to preserve the benefits of having human-centered design activities and goals, as they are the core of creativity in functional designs (Soulikias Et al., 2021). Sinnamon agrees with Soulikias stating that, in addition to improving creativity, human interaction plays an important role in the spatial awareness of the designers within the design process (Sinnamon Et al., 2022) as designers get to experience designs in person and introduce changes accordingly. Hence, approaches like Kourteva and Mc Meel's that promote the usage of digital media technologies as supportive factors to human driven architecture and building production design process rose in relevance (Kourteva & Mc Meel, 2017) as it incorporates the benefits of both digital media and physical approaches. Alatta and Freewan further validated this sentiment but with a different approach, as they used digital media to simulate real life settings through virtual environments to help designers better realize their designs (Alatta & Freewan, 2017) by using virtual reality (VR) for realistic

immersion. This approach makes human intervention more incorporated into digital media, rather than relegating digital media to a supportive role.

The incorporation of human activity introduced by digital media helped improve the inclusivity of the architecture and building production design process, as it enables any individual to partake in design activities. Ozdemir studies showed that this can be seen on a larger scale through design personalization (Ozdemir Et al., 2022) where individuals or clients can partake in the design process and introduce changes according to their needs. Mussi expressed another form of inclusivity by incorporating people with disabilities into the architecture and building production design process to integrate their feedback into the design as future users or as designers within projects (Mussi Et al., 2021). Finally, Ma, Özer, and Kavakoğlu viewed the potential of integrating human interaction into the architecture and building production design process as a design parameter, where activities are included as variable parts of the design which are controlled and manipulated by the designers (Ma Et al., 2021; Özer & Kavakoğlu, 2017).

2.2.1 Image Processing

In its simplest form, image processing technologies are used to alter, manipulate, or enhance digital images (2D or 3D image) to create a new output image to achieve a specific goal of either improving its quality or add, change or manipulate it. (Corke, 2021). Image processing isn't limited to improving the visual qualities of images, it can be used to combine multiple images into collages to help present information more clearly. Additionally, it is used to enhance digitally produced images to improve their ability of relaying data in a more convincing manner (Huang, 2016). This is done by manipulating images to seem more realistic, adding elements to the images to improve visual clarity, and

imposing digitally produced images over realistic pictures. Image processing is applicable to both two-dimensional images like technical architectural drawings, and to three-dimensional images like renders of project and pictures of existing sites. There are two types of image processing technologies that differ in the way they manipulate images, pixel-based and vector-based technologies.

Pixel-based image processing technologies handle images in the form of pixels, where each image imported or produced is converted into a group of pixels that are independent of each other. Each pixel represents a color value and together they form the image seen. Different groups or layers of pixels can exist simultaneously to facilitate more complex manipulations without combining the different sets of pixels. Though each pixel is independent of the others, transformations within the same layer of pixels often result in the deletion or replacement of other pixels in the process. This technology has the advantages of easy color manipulation, small file sizes, and the ability to easily modify existing images; While disadvantages are that selections and paths can't be retrieved, it's inconvenient for creating new images, and it loses quality beyond the initial dimensions of the images.

Vector-based image processing relies on a different kind of technology where images are stored in vectors instead of pixels. This method of image processing allows for more fine-tuned manipulations and more accurate image creation. Produced images are stored as directional vectors, with properties and dimensions that can be manipulated at any time. This allows for more control while giving more flexibility for exploring alternatives. Even existing images can be automatically transformed into vectors for ease of integration within the technology. Alas, it has the advantages of fine-tuned controls, easy creation of new

images, quick manipulation of vector properties, and the storage of vector data. However, its drawbacks are that it can't directly edit images, in addition to being limited by the vectors' paths, and finally their inability to edit colors of images.

Popular software packages, like Adobe Photoshop and Illustrator, use a mix of both technologies to minimize the effects of the shortcomings of both technologies. Although, each has their own uses. Sondermann stated that Pixel-based image processing focuses on image manipulation and collaging while vector-based technologies focus on the creation of completely new images (Sondermann, 2009). In the context of architecture, Min stated that pixel-based technologies are best used to enhance computer generated images (Min, 2010) while Liu stated that vector-based technologies are better used for diagramming (Liu Et al., 2018). Moon's findings align with those sentiments, stating their essentiality for the clarity of presentation phase (Moon Et al., 2022).

2.2.2 Computer Aided Architectural Design

Computer Aided Design (CAD) is an old concept that rapidly developed to a comprehensive and essential part of most industries. The first significant development to CAD was in 1969 at MIT, where Ivan Sutherland introduced the Sketchpad; Sketchpad was a strictly two-dimensional graphical presentation software that allowed plotting points and creating lines on an X and Y axis. Sketchpad facilitated the development of development of two-dimensional CAD software; However, it wasn't incentivizing enough to rationalize a complete shift from manual production, hence both methods coexisted ("The History of CAD," 2004). The introduction of one of the most used CAD software, AutoCAD, in 1982 was a major catalyst in the development of the accessibility of CAD,

both three-dimensional and two dimensional. By the early 1990s, all CAD technologies were readily available for personal usage (“The History of CAD,” 2004).

Contrary to general belief, the differentiation between two-dimensional and three-dimensional CAD technologies isn’t by the number of dimensions in which they operate but by the functional capabilities of the final product through the software. As defined by Brown, two-dimensional CAD is comprised of wireframing that creates shapes with no volumes or masses. Traditional three-dimensional wireframing introduced volume to the product but without any physical mass. Finally, modern CAD technologies produce three-dimensional solid models; These models have their shape, mass and volume included. This allows the users to add simulated physical properties to the model (density, texture, materials, etc.) to the product created using CAD technologies (Brown, 2009).

Computer-Aided Architectural Design (CAAD) is a term that was established early in the development of CAD. It relates to the usage of CAD strictly within the context of architectural design. Lawson attested that the biggest challenge in the development of CAAD is the misunderstood nature of the architectural design process and how it affects the implementation of CAD technologies (Lawson, 1998). In concurrence with Lawson, prominent researchers in the fields of digital media and architectural design categorizing CAD technologies based on their functionalities, ensuring the methodological advancements of CAAD were properly aligned with the architectural design process, in turn allowing for concise development. The aforementioned categories are as follows (Mitchell, 1975; Gero, 1983; Kalay & Mitchell, 2004):

- Improvements in visualization

- Three-dimensional modelling (not exclusive to graphical representation)
- Performance prediction and simulation
- Algorithmic and automated design solution production
- Big data management
- Virtual collaboration capabilities

2.2.3 Building Information Modelling (BIM)

Building Information Modelling (BIM) focuses on the continuous availability of accurate data throughout the design process. This allows for an iterative interactive design process (Parsaee & Motealleh, 2015) where designers can easily test the performance of multiple variations of the designs (Bayar & Aziz, 2018) while simultaneously optimizing them for maximum efficiency (Kim, 2019; Megahed, 2015). Boyd conducted a comprehensive study to test the effects of integrating BIM into a multi-disciplinary building project, it led to multiple key findings like highlighting the importance of the use of three-dimensional visuals and the inability of BIM to be applied unless some imaginary perfectionist setting is used as the context of the project. It doesn't mean that the context isn't real, it just means that it is slightly altered to allow for proper application of BIM. Additionally, the study further stresses the fact that BIM isn't applicable in the conceptual design phase and heuristics remain as the prominent way of making decisions (Boyd, 2021).

Multiple approaches for the use of digital media to create a fully integrated design process in a professional setting were explored. Popovic experimented with using BIM to allow designers to create design modules which fit a particular project with given parameters (Popovic Et al., 2021), while Lobos focused on using BIM in combination with parametric design to target and proposed design solutions to a particular architectural problem (Lobos

Et al., 2010), while Krishnamurti focused on using BIM systems as a guiding way which helps direct the design process towards achieving sustainable goals (Krishnamurti Et al., 2013). Paavola and Miettinen explored the uses of BIM as a bridging method between different design process, as it can be used as a form of accurate presentation of data, making problem solving a much simpler approach as a lot of solutions can be proposed in a dynamic way (Paavola & Miettinen, 2019).

The integration of digital media into professional practice has a lot of clear advantages. Though the infrastructure needed for the adoption and integration of digital media into the various stages of the design process may be a jarring task, the benefits and the massive improvement in the quality and level of detail of the project make it a very worthwhile investment. Chang and Shih stated that the adoption of digital media also improves the integration between different disciplines within the architecture and building production field, whether it be horizontal integration between different teams or vertical integration throughout different phases of the project (Chang & Shih, 2013). Stals developed a simple design process that eases the incremental introduction of digital media, which can then be scaled with time (Stals Et al., 2021). Stals concluded that BIM in combination with parametric design methods are the enablers for the adoption of digital media into the architectural design process regardless of scale of operation. The proposed model by Stals separates the design process into two smaller processes, one which is responsible for creating a solid concept which is fully traditional, and the second part fully depends on parametric design methods. This process is supposed to eliminate the need for going back into the conceptual design process by eliminating it from the BIM system, as the erratic nature of this phase would introduce a lot of difficulties for the initial adoption process.

With the recent rise of the popularity of building rating systems, most notably sustainability rating systems, digital media technologies revolving around facilitating the achievement of good ratings were developed and explored. For example, in reference to the American Leadership in Energy and Environmental Design (LEED) and the British Building Research Establishment Environmental Assessment Method (BREEAM) sustainability rating systems, Salgueiro and Ferries developed an “Environmental BIM” for conceptual and early design phases; This approach introduces ten environmental criteria, which are managed using BIM, to be added to the conceptual design phase to provide vital information for future design phases in order to adhere to the standards set by said sustainable systems (Salgueiro & Ferries, 2015). Lee supported this approach, stating that an integrative design process is crucial to achieve a good sustainable building rating (Lee, 2010). Furthermore, Zanni introduced sustainable building design (SBD) to provide a clear path which can be followed to achieve such ratings. SBD is an addition to BIM which identifies the personnel, tasks and every other aspect which needs to be covered for the design to be successfully sustainable (Zanni Et al., 2016). A comprehensive integration of digital media into the architecture and building production design process is crucial for good building ratings. The term BIM enabled sustainable building design (Zanni Et al., 2020) is used to describe a BIM system which aims at creating a completely sustainable building. Finally, it is worth noting that simple BIM applications like the one introduced by Stals tend to avoid the conceptual and schematic design phase, while more developed applications tend to include it as it’s crucial for efficient design development and optimization.

According to Mohammed, the introduction of BIM helps quantify external factors that affect design decisions and include them in the decision-making process, which was shown to be effective for environmental and sustainability factors (Mohammed, 2020). Furthermore, Güzelci agreed with this notion, stating that the integrating of BIM into the design process can lay a solid foundation for easier design decisions in general, as any performance indicator can be easily accessed and assessed at any time (Güzelci Et al., 2022).

2.2.4 Parametric Design Tools

Woodbury defined parametric design as a form of digital media technology that incorporated mathematical algorithms into design geometries (Woodbury, 2010). According to Chen, it facilitated easy manipulation of forms throughout the architecture and building production design process when compared to traditional design activities (Chen Et al., 2015). Gramazio and Kohler argued that this method of design helped popularize complexity in the designs produced up to the point where the focus was shifted to creating overly complicated geometries instead of having the complexity be in the details and thought put into projects (Gramazio & Kohler, 2008).

Oxman and Gu discovered that due to the rise in the usage of parametric design in architecture and building production design processes, it manifested its own identity within the design sector (Oxman & Gu, 2015) where the use of these digital media technologies resulted in the creation of their own design style and methodology which is known as parametric design thinking (Oxman, 2014). However, despite the inherent complexity of these digital media technologies, a lot of designs are very similar to one another. Gourdoukis argued that this homogeneity was consistent due to the nature of these digital

media technologies, and not because of the designers adopting them (Gourdoukis, 2018; 2019). In attempts to eliminate ambiguity from design, creativity was lost. Which is why variability can only be reintroduced by avoiding the uniformity introduced by digital media as limitations, and adopting them as tools for exploration and maintaining creativity as input from human intervention (Gourdoukis, 2020).

2.2.5 Big Data

The accessibility of data and its availability is a significant factor in the development of digital media. This reasoning is why Neef concluded that “Big Data” has been adopted into the architecture and building production design process (Neef, 2014). Ham shares this sentiment with Neef, stating that big data is crucial for collaboration due to its constant real-time updating of data while providing accurate estimations, using cross-referencing, about relationships which aren’t implicitly stated (Neef, 2014; Ham, 2012). Delso and Sánchez-Vaquerizo referred to big data’s role in highlighting the responsibilities of designers in data collection (Delso & Sánchez-Vaquerizo, 2018). Additionally, Meekings and Schnabel focused on big data’s role in communication about projects between stakeholders, including details about all the personnel relevant to the design process (Meekings & Schnabel, 2017).

All aspects of data are equally important for designers. Where Zanchetta highlighted the incorporation of socioeconomic and environmental aspects into the architecture and building production design process using big data (Zanchetta Et al., 2017), while Sydora and Stroulia focused on enterprise-imposed regulations (Sydora & Stroulia, 2020). Kim stated that big data allowed data presentation developments that allow for clear presentation of different combinations of data throughout the architecture and building

production design process (Kim Et al., 2018), this notion was further supported by Sydora and Stroulia's research where they accentuated the possibility of retroactively highlighting any critical issues in designs by automatically comparing designs to various data sets (Sydora & Stroulia, 2020).

2.2.6 Machine Learning and Artificial Intelligence

According to Tecuci, artificial intelligence refers to technologies that adopt the approach of developing digit systems that simulate behaviors characterized by human intelligence (Tecuci, 2012). Deng expanded on that definition stating that these systems focus on the use of algorithms to either simulate or extend the capabilities of human intelligence in performing tasks (Deng, 2018). It is important to note that artificial intelligence technologies and systems are reliant on their original algorithm for the way they assess and analyze information, meaning that the way they simulate human intelligence is confined to their original intended use. Though agreeing with Tecuci and Deng, Kaspar noted that artificial intelligence technologies aren't truly capable of simulating human intelligence and decision-making capabilities in unbounded contexts that require critical subjective thinking but are suitable for intensive repetitive objective cognitive tasks like classification and recognition of patterns (Kaspar Et al., 2021). AJuhi noted that due to the efficient usage of artificial intelligence in pattern recognition, they are also useful for making future predictions based on the recognition of patterns and identifying factors lead affect them in addition to any repetitive trends observed from the data sets analyzed (AJuhi Et al., 2020). Additionally, Camargo emphasized that artificial intelligence systems are as good as the data used to train them; More extensive data sets used to train the systems lead to more accurate and reliable outputs and predictions (Camargo Et al., 2022).

Machine learning is a branch of artificial intelligence that is centered around the optimization of algorithms and the systems they are used in. Jordan described its functionality as recursively analyzing the inputs and outputs of the system to assess the accuracy of the system, then automatically learning from those processes to improve the internal algorithms that are responsible for decision-making (Jordan Et al., 2015). Machine learning also uses training data sets like artificial intelligence but has the added advantage of constantly improving beyond that initial learning phase.

The usage of artificial intelligence and machine learning technologies has minimal downsides in general. Vinod stated that, excluding the considerable technical knowledge needed to develop a system that is efficiently effective at doing its intended tasks, most of the drawbacks are related to ethics and the introduced effects on society (Vinod Et al., 2022). These ethical issues include loss of jobs, questionable future usage, and proper regulation of those systems. Furthermore, Ferretti argued that one major technical ambiguity with the usage of those technologies is their black box nature, where the decision-making process and the logics behind it remain opaque to understanding (Ferretti Et al., 2018). Assumptions can be made by analyzing the outputs compared to the inputs, in addition to referencing the algorithms' code, but those don't represent the full logic followed by the system in a satisfactory manner. Additionally, Pedreschi highlighted that these systems are susceptible to human biases affecting their logic and skewing data to conform with prejudices that are often hidden as collection artifacts in data sets used for the initial training (Pedreschi Et al., 2019).

Being an extremely popular field since its inception, artificial intelligence and machine learning were adopted into various industries throughout the years. Dixon realized their

potential within the architectural and building production design process very early, as these technologies' capabilities perfectly matched the requirements needed for evaluating and proposing redesigns throughout projects (Dixon Et al., 1984). Artificial intelligence is used in more robust areas of the architectural design process, while machine learning is used in areas where continues learning and leniency in logic development is needed. Mehmood highlighted some applications of artificial intelligence including the development of energy-efficient designs, reduction of energy consumption, forecasting, and load predictions (Mehmood Et al., 2019). Additionally, artificial intelligence can eliminate many time-consuming repetitive tasks. This approach was adopted by Seo when developing artificial intelligence systems that can be used to infer technical architectural drawings to identify and translate those characteristics automatically onto a CAD drawing to eliminate tedium from the design activity (Seo Et al., 2020). Finally, Hamdaoui stated that artificial intelligence functions exceptionally with data-based technologies like parametric design, where the parametric elements' data and relationships are used directly by the artificial intelligence system to propose quantitative performance optimizations to the design (Hamdaoui Et al., 2018).

Machine learning systems are used in applications that require real time analysis in addition to continuous learning, as these activities have no objective definitive correct approaches. They are heavily used to improve the efficiency of tedious tasks that are highly prone to human error. Bhatnagar showcased the efficiency of machine learning technologies in the supervision of construction documentation production, comparison and culling of design alternatives, and managing basic human resource activities like attendance and leaves (Bhatnagar, 2020). These systems can be run completely independently from any human

input or can be implemented in parallel with human intervention as a safety measure. Additionally, Zheng proposed that machine learning can be used to directly improve the accuracy and efficiency of the architectural design process. This is possible by using vector-based two-dimensional CAD drawings to predict architectural design solutions based on the designs' ongoing development (Zheng Et al., 2020); Zheng further explored this approach on a three-dimensional scale by using variable-based technologies like BIM or parametric design tools, where machine learning helps designers to adopt a faster and more precise data-driven approach for generating and analyzing alternative architectural designs based on quantifiable variables and measurements (Zheng Et al., 2021).

2.2.7 Simulations

Simulations are a well-established technology that has been developed continuously over the years both digitally and analogously. Cellier proclaimed physical model-making as the original form of simulation, where it creates a scaled version of systems to analyze their performance and improve understanding of their physical properties and intricacies, which in turn allows for performance predictions to be made prior to construction (Cellier, 1991). Brynjarsdóttir supported this old sentiment, acknowledging that physical models are still useful in the current day, namely for calibrating and validating digital simulations to ensure the accuracy of their prediction-making capabilities (Brynjarsdóttir Et al., 2014).

Bandini defined simulations as the act of using digital models to enhance the understanding of the behaviors of systems and to evaluate their operational strategies in an explanatory scheme or for predictive purposes (Bandini Et al., 2009). Another definition established by Peng states that it is the imitation of real-life systems in a realistic digital replica to represent key behaviors and characteristics (Peng, 2020). Ören highlighted that simulations

are specific in nature, meaning that they can only simulate portions of the characteristics of systems that are relevant to the data needed (Ören Et al., 2019); Simulating all the characteristics of a system is often redundant and slows down the simulation process for no added benefits, hence the goal-nature of simulations.

In architectural design, simulation is used to model different systems to enable the creation of more sustainable, functionally feasible, and technically compelling architectural product; These include thermal, lighting, electrical loads, user behavior, structural integrity and more (Goldstein Et al., 2017). Clayton showcased that these simulations can be used to present different phases of various processes by presenting their different phases of implementation through time-lapse animations (Clayton Et al., 2002). Finally, Antonino's research inferred similar sentiments as Clayton's, stating that simulations are an essential part of the architectural design process as they are the only way to quantitatively evaluate different design proposals in comparison to the required specification of the architectural product and assess the effects of different systems' approaches collectively on the whole project (Antonino Et al., 2018).

2.2.8 Digital Fabrication

Digital fabrication is a growing area within the architecture and building production sector. Ng noted that due to its extremely technical nature, the adoption of such a form of digital media is usually accompanied with a systematic rethinking of entire areas of the architecture and building production design process to fully realize its benefits (Ng Et al., 2022); The most prominent areas of exploration in literature that are relevant to the architecture and building production design process are technical development, technological systems, and organizational contexts. Contractual provisions and business

models are also being explored in terms of business development and managerial operations.

In studies focused on technical development in practice, digital fabrication allowed for increased freedom in design (Law Et al., 2022; Ng Et al., 2021), improved productivity and efficiency (Bock, 2015; Law Et al., 2022; Pan & Pan, 2020; García de Soto Et al., 2019), heightened on-site workers' safety (Kim Et al., 2022; Law et al., 2022), and allowed for collaboration of all relevant personnel by providing a virtual environment that facilitates such collaborations (Weng Et al., 2021).

Literature concerned with the technological systems of digital fabrication were mainly focused on the systematic requirements that facilitate the proper adoption of digital fabrication. These included a common environment where data is linked (Bock, 2015), the certainty of the accuracy of the data available for usage (Law Et al., 2022), and most importantly the accessibility and sharing capabilities of the data used (Bock, 2015; Hall Et al., 2020; Hwang Et al., 2022; Ng Et al. 2021). All the aforementioned requirements can be satisfied by adopting BIM for the storage and presentation of data for the digital fabrication processes (Ravi Et al. 2021; Teizer Et al 2018).

In an organizational context, the adoption of digital fabrication introduces a lot of benefits to the individuals involved in the architecture and building production design process. As the introduction of digital fabrication enhances the general organizational integration, it resulted in a growing environment of knowledge sharing and professional growth between personnel within the organization; this also resulted in an increase in the level of trust in

digital media (Hall Et al., 2020; Ng Et al., 2021; Pan & Pan 2019; 2020; García de Soto Et al., 2019).

Digital fabrication isn't just an added tool to help realize designs which were previously difficult but is a catalyst for these designs (Fallacara & Barberio, 2018); The growing adoption of digital fabrication led to the development of design trends and approaches which are focused around showcasing complex forms for their manufacturability rather than purely aesthetic reasons (Chiarella & Alvarado, 2015). This trend is also supported by digital media's capabilities of handling complex three-dimensional designs and creating constructible parts that translate it into real objects regardless of geometric intricacies or materials used (Agkathidis Et al., 2019; Willmann Et al., 2016).

2.3 Information Flow Across Applications and Design Team Members

The architectural design process is heavily reliant on efficient information flow throughout the entirety of its duration. Phelps argued that this is because decision-making relies on the availability of data to make informed decisions, so any scarcity in information availability or accuracy will usually cause conflicts that will hinder the smooth progression of the design process, which is much more apparent in larger complex projects (Phelps Et al., 2008). Austin shared similar sentiments to Phelps, stating that a lot of design activities are dependent on other activities' completion, so efficient information flow is crucial in preventing the overlapping of interdependent activities; Especially when tackling multi-disciplinary architectural design problems (Austin Et al., 1996; 1994). Hence, Tribelsky established that the quality of information flow, both in terms of data availability and communication, is positively correlated with the documentation phase's effectiveness (Tribelsky Et al., 2011). Which in turn supports Shahid's recommendations for avoiding

problems and delays in architecture and building production design process (Shahid Et al., 1998).

2.3.1 Conventional Information Flow

Conventional information flow refers to the basics of information transfer throughout the architectural design process. This isn't detached from the reliance on digital media but focuses on the fundamentals that shape the methods that information is processed and made available within the different design phases of the architectural design process. According to Eppinger as the architectural design process is a creative ordeal, it is more concerned with what information is needed to complete a task rather than what design activities need to be done before beginning others (Eppinger, 2001). Bashir and Baldwin stated that generic information flow approaches can be applied to the architectural design process for immediate basic benefits, but they fail to utilize and properly manage the haphazard direct and indirect information flow between the different activities within the architectural design process (Bashir Et al., 2020; Baldwin Et al., 1999). Hence, Eppinger established the following guidelines to enhance conventional information flow within the architecture and building production design process (Eppinger, 2001):

- Changing the sequential approach and organization of design tasks based on information availability and the data produced by said tasks.
- Minimize needed information exchange frequency.
- Incorporate the management of unexpected work into the information flow.

Emphasizing conventional information flow's reliance on digital media usage, Jeng highlighted that digital media technologies facilitate better collaborative approaches,

enhance communication within the architectural design process, and to improve information flow (Jeng Et al., 1999). This still lies within the realm of conventional information flow though, as digital media is used to store rather than transmit information. The latter approach is called computer-mediated information flow.

2.3.2 Computer-Mediated Information Flow (synchronous and asynchronous collaboration tools)

According to Nardi, computer-mediated communications are crucial for the efficient success of collaboration-dependent work that is moderately reliant on digital media usage (Nardi, 2005). Nardi further explained computer-mediated information flow is an evolution of the computer-mediated communication concept, where communications are confined within isolated instances of information exchange (Nardi, 2005). This is further supported by Mbakop's description of information flow, which states that it covers the entirety of communication activities and the availability of the data obtained from them throughout the different phases of the architectural design process (Mbakop Et al., 2021).

Pesendorfer stated that computer-mediated information flow is achieved through two types of tools that facilitate different types of communication, synchronous and asynchronous collaboration tools (Pesendorfer Et al., 2006). Synchronous collaboration tools enable real-time communication between individuals, which tends to be more argumentative and competitive due to their quick paced nature. These tools allow for immediate information exchange and timely feedback with no delays in response. Asynchronous collaboration tools allow communication to happen whenever suitable, while allowing information to be available prior to partaking in the communicative activity. Though communications can be

delayed, this approach results in friendlier objectively task-focused behavior from individuals.

The architectural design process is very vast with many different phases and supportive activities happening simultaneously and codependently, hence different combinations of the aforementioned collaboration tools are used based on their suitability to the tasks being undertaken. This tendency can be seen in digital media applications developed for the enhancement of information flow. Two main approaches summarize the research realm of optimizing information flow using digital media technologies, automated and collaborative data flow. Automated data flow are explorations where digital media is used to automatically transfer information between different activities from different parts of the architectural design process, allowing for instant data availability. This is done in an asynchronous manner, where information is accessible once it is intended to be. Collaborative data flow refers to a synchronous approach that has multiple individuals access and work on files that are interconnected and update in real-time, resulting in data being available to all relevant personnel immediately. Multiple people can access and edit the same file simultaneously, in addition to knowing who is currently working or has introduced previous edits.

BIM is the most prominent digital media technology in developing information flow optimization applications. Jung stated that this is due to its inherent extensive data storage capabilities, which can be utilized to readily share information that eases decision-making in complex tasks (Jung Et al., 2014). Luo explained that this directly results in improvements in coordination between design activities and better utilization of resources throughout the architectural design process (Luo Et al., 2014). Rathnasinghe agreed with

this notion, especially when considering the complexity and magnitude of information flow between all the stakeholders and relevant personnel (Rathnasinghe Et al., 2020). Finally, Boje highlighted the fact that a fully realized BIM application with extensive information flow optimization forms the basis of a Digital Twin, which is an accurate digital replica of a design product that can be used to accurately predict the details of the full design process, allowing for optimizations to be made proactively to maximize efficiency and minimize any shortcomings throughout the architectural design process and the architectural product's life cycle (Boje Et al., 2020).

Industry Foundation Class (IFC)

One of the breakthroughs that digital media introduced into the architecture and building production field is the ease and availability of information throughout the entirety of the design process. The nature and types of data needed change depending on the task on hand, but digital media removed the adversity from the access of data in a timely manner. Meekings and Schnabel stated that this is mainly facilitated by the incorporation of big data, which had a major effect on the workflow (Meekings & Schnabel, 2017). The data made available ranges from real-time real-life data obtained directly from sites (Kowalewski & Girot, 2021) to data produced by different parts of the design team for various reasons like optimization of designs (Vite & Morbiducci, 2021), building performance prediction (Zanchetta Et al., 2017), or urban scale analysis (Cattaneo Et al., 2016).

With constant developments in digital media resulting in information being available throughout the design process, Granda and Bello observed that decision making was

impacted positively due to the reliance on digital media (Granda & Bello, 2021). According to Meehan & DuRussel, this is mainly due to the availability of data throughout the design process resulting in better-informed design decisions to be made (Meehan & DuRussel, 2020). Alvear added that the data itself can be presented in various forms using purpose-made digital media technologies (Alvear, 2020) depending on the level of detail and amount of data required.

As digital media becomes deeply rooted into the architecture and building production design process, the timeline of the design process as it progresses through the different design phases has also been digitalized. IFC (Industry Foundation Class) is a file format developed to maintain the attributes of digital models while being readable by different software packages. By using algorithms, IFC files have been used to showcase the digital footprint of design processes while maintaining the attributes relevant to each time period, allowing for easy access to any older version (Kouhestani, & Mazdak, 2020). IFC's flexibility and extreme compatibility with digital media is a strong reason why the documentation process has been greatly improved with the adoption of digital media. Having a universal file format parallels the utility provided by traditional manual presentation methods, as any personnel can access and understand the documentation through any convenient software package, paralleling the act of design team members discussing technical documents printed on a paper. With the growing interest in maintaining the footprint of digital media, Singh and Willcox developed the concept of a digital thread. A digital thread is a form of digital media algorithm that automatically stores all iterations of the design product throughout the entire process, allowing solutions to be

explored through multiple variations at various steps of the design process (Singh & Willcox, 2021).

2.4 Studies of the Adoption and Diffusion of Digital Media in Architecture

option and diffusion are key characteristics in the process of introducing digital media into new contexts. The two are representative of the same phenomenon but differ in respect to the extent and depth of the introduction of technology. Pierce described the adoption of digital media as the initial introduction and implementation of the technologies into the new context (Pierce Et al., 1997). Francis further elaborated that adoption also covers behavioral reception of the context's personnel regarding the introduction of new digital media technologies, as said introductions may induct personal and interpersonal demeanor changes (Francis Et al., 2004). On the other hand, Mahajan described diffusion as happening over a longer period of time where newly adopted digital media technologies are continuously being used in their new context (Mahajan Et al., 1990). Vargo further expanded Mahajan definition, stating that diffusion considers all social and work-related factors through an extended duration, where these factors are recursively changing and simultaneously affecting the diffusion process (Vargo Et al., 2020). In conclusion, Chandrasekaran comprehensively covered both adoption and diffusion, stating that adoption is the initial phase of introducing digital media technologies while diffusion covers the intricacies of constant usage and implementation after the adoption process has occurred (Chandrasekaran Et al., 2010).

2.4.1 Adoption of Digital Media

Digital media innovations are constantly introduced in various contexts that have their own unique characteristics. However, studies focusing on the adoption of digital media identified some general similarities that exist regardless of the context of adoption. Carlo categorized digital media technologies' adoption into three categories (Carlo Et al., 2014):

- Basic technology adoption
- Services production
- Process adoption

These categories form a base for the requirements of successful adoption regardless of the purpose of the technology itself. Additionally, Carlo deduced that whether the adoption is early or late plays a significant role in affecting the characteristics of the adoption process. It mainly impacts (Carlo Et al., 2014):

- Adoption rate
- Acceptable adoption amount
- Perceived radicalness
- Acceptable perceived radicalness

Adoption of digital media is done for various purposes, some of which relate to the competitiveness of their market and context. Chiu noticed through his study that businesses tend to adopt digital media to maintain competitive advantages, while acknowledging that the type of digital media technology and the context of adoption are what determines the extent of the acquired advantage (Chiu Et al., 2019). Though Xiao-fang argues that adoption tailored to market competitiveness isn't effective and is very prone to sunken cost

fallacies while being a process suffused with uncertainty (Xiao-fang, 2007). Mofakhami covered the topic from an employee's perspective, stating that digital media adoption improves employment quality but increases the intensity of the typical workday; This indirect heightened physical requirement highlights the need for regulations to ensure the wellbeing of employees throughout the process of business development (Mofakhami, 2021).

Finally, it is important to note that digital media adoption is also dependent on individuals' sentiments towards the digital media technology. Ellen noted that satisfactory performance and efficacy are significant influences that focus on the technology itself (Ellen Et al., 1991), while Kulviwat added that general social sentiment towards the adoption of digital media is another significant context-focused influence that impacts the adoption process (Kulviwat Et al., 2009).

Adoption Within the Context of Architecture

The architectural design process consists of various activities being undertaken codependently. Magnusson identified that due to this characteristic, adoption procedures must be done discontinuously where the adoption of digital media technologies is procedurally done in small batches rather than being fully introduced (Magnusson Et al., 2003). El-Shorbagy expanded Magnusson's findings, stating that discontinuous adoption also includes both organizational and physical accommodations for the technology, where organizational adjustments systematically affect the workflow while physical accommodations' effects are confined to regions that directly interact with the innovation (El-Shorbagy, 2021; Magnusson Et al., 2003).

Ramilo highlighted that adoption of digital media in practice varies based on the size of the architectural design firm, where different factors vary in significance relative to the preparatory measures required to ensure successful adoption (Ramilo, 2014). Ramilo further explained that small-sized practices require major organizational and psychological preparations, whereas medium-sized practices need significant financial reserves to support the adoption process and the required technological training accompanying it, and large practices need to actively and retroactively restructure their organizational processes to accommodate the adoption (Ramilo Et al., 2014). Wang's assessment of the effects of governmental regulations and policies resulted in finding that the influence on the adoption process depends on the country, but they don't have any negative influence as they either act as driving factors for adoption (Wang Et al., 2021) or are irrelevant to the adoption process as stated by Ramilo (Ramilo Et al., 2014).

Almuntaser stated that the adoption of digital media technologies in the architecture and building production sector contributes to the betterment of information usage, architectural design process speed, and satisfaction of clients (Almuntaser Et al., 2018). However, Ghaffarianhoseini argues that it is still considered to be an excessively demanding ordeal that requires efforts that are inconsistent with the perceived returns on investment acquired, as the disruption introduced by the adoption process significantly hinders the workflow for the duration of the adoption (Ghaffarianhoseini Et al., 2017). Belete agrees with both Ghaffarianhoseini and Almuntaser, stating that this highlights the need for the development of implementation strategies that help guide the adoption process in the architecture and building production field (Belete Et al., 2020) instead of the commonly adopted professional-dependent approach (Almuntaser Et al., 2018) where an individual's

experiences are used as absolute guidelines for the adoption process. Finally, Jaspers emphasized the importance of the development of those strategies for establishing digital media adoption foundations within interdisciplinary contexts, where the involvement and coordination of specialists from different disciplines is essential for effective decision-making (Jaspers Et al., 2021).

2.4.2 Diffusion of Innovation and Digital Media: A Theoretical Framework

Precedent to exploring the concept of innovation diffusion, it is essential to analyze the basic key concepts' evolution throughout history. In literature, innovation is an extensively scrutinized concept with continuous development to its understanding. In consensus based on the number citations and the dependency of later studies on them, there are four prominent references, which cover the perspectives of their relative authors, that are considered as the foundation of innovation research. These definitions are:

- Everett M. Rogers' definition (Rogers, 1962).: Rogers' works are known for being major proponents of the basic concept of innovation diffusion. In the book "Diffusion of Innovations", written by him, innovations are described as ideas, practices or even physical objects that are considered new by any adoption unit. They don't necessarily need to be exclusively new; If they're perceived as new within their context according to the individuals interacting with them, they are considered as innovations.
- Gerald Zaltman and colleagues' definition (Zaltman et al., 1973): In the book "Innovations and organizations" innovations are defined as any ideas, concepts, processes, or material objects that are perceived as new additions to the context

they are being introduced to. Though very similar to Rogers' definition, the main difference is that they focus on organizational contexts rather than an individual level. This definition is extensively adopted in studies regarding organizational innovation as it links innovations to real life managerial and organizational scenarios (Wagemans, 2001).

- Andrew H. Van de Ven's definition (Van de Ven, 1986): This interpretation of innovation is entrenched in both Rogers' and Zaltman's premises. It states that an innovation is comprised of two identifying factors, the new idea, and the context. In addition to original unique ideas, a new idea may also be a recombination of existing ones, a change in systematic structure, or a different approach to a task. The context according to Ven is the setting where new ideas are perceived to be new by the individuals involved. Perception is key to Ven's definition, as the importance of imitation is highlighted as the dominant way of appropriating innovations within organizations.
- Joseph Schumpeter's definition (De Jong and Den Hartog, 2003): Having an economist perspective, Schumpeter is considered a pioneer in focusing on innovation within an economical context (Rogers, 1998). According to his book "The Theory of Economic Development", innovation is the formation and application of new combinations. They proposed five main types of innovations (OECD, 1997):
 - New products or partial changes in existing products
 - New processes within an industry
 - The creation of new markets

- Development of new sources for raw materials (or other inputs)
- Organizational changes within an industry

Hence, by definition, innovation diffusion is a process where new theories, ideas, or any new approaches are voiced over periods of time between individuals in a particular social system, where the process is comprised of four key factors (Rogers Et al., 2014):

- Innovations: These are the creative outcomes of the efforts of individuals. They can be products, techniques, technologies, or even systematic approaches. Any new or improved product, regardless of its nature, is considered an innovation.
- Communication channels: The methods that are used by individuals to share and discuss innovations within a social system.
- Time: This refers to both the relative time of the introduction of an innovation in relation to its relevant context (i.e., lateness or earliness) in addition to the speed of diffusion.
- Social systems: These are social constructs that relate individuals based on their interests in accomplishing similar goals or solving similar problems.

Additionally, the context of which the innovation diffusion is taking place plays a role in the process. According to Rogers, context can be defined in terms of social structure and system norms. Social structure relates to the interpersonal relationships between individuals of any system, whereas the system norms refer to the generally accepted behaviors within a system that may be acceptable or inappropriate (Rogers Et al., 2014). Though different everywhere, Zerfass stated that the context majorly affects the successful implementation and adoption of innovations. They added that Insufficient communication

concerning innovations, regardless of reason, directly correlates to failure in adoption (Zerfass, 2005).

Within the wider field of research, innovation is the resultant outcome of a complex system of interactive communications and social relationships (Bain Et al., 2001; Egbu Et al., 1998). Hence, it can be deduced that innovation is very closely related to social psychology due to its success being reliant on social interactions between members of a social system. Social psychology is the way that feelings, thoughts, intentions, actions, etc., are affected by the other individuals' presence within their lives (Grotjahn, 1954). It is worth noting that the presence of an individual can be physical, implied, or even imaginary. Presence in this context is relevant to the users, and its implications are completely dependent on the users' perception. In this vein, Ashforth developed the concept of innovation climate which describes the social influence on innovative tendencies on individuals, which's effect on innovation tendencies parallels that of social psychology (Ashforth, 1985).

In an organizational context, the climate of innovation plays a major role in motivating innovative activities and tendencies. Amabile explained that from a general members' perspective, the perception of innovation and its adoption within an organization is a significant motivator for further innovative ideas to be generated (Amabile Et al., 1996). Dulaimi added to this sentiment, stating that it is paralleled by the organizations' responsibilities in promoting innovation through communication with the members of the organization and aligning the organization's goals with expectations of innovation (Dulaimi, 2005). In the field of architecture and building production, the innovation climate can be represented by three constructs based on interconnected socio-psychological

aspects: Leadership, team climate, and organizational structure (Panuwatwanich Et al., 2008).

Though it introduces a lot of benefits for organizations, Zaltman states that diffusion of innovation is a socially disruptive practice in nature (Zaltman Et al., 1973). Rogers agrees, highlighting that these disruptions are because of changes introduced to the systematic structure and functions of the social system it was introduced in (Rogers Et al., 2014). Organizational readiness, which is described by Martin as an organization's preparedness to handle the disruption of the adoption and implementation of innovations, is important in mitigating the risks introduced (Martin Et al., 2008). This is consistent with the aforementioned studies that emphasize the importance of managerial and organizational efforts in both the diffusion and the creation of innovations; This notion is further emphasized by the fact that an organization's readiness can be determined by analyzing its leadership and the general work culture within the organization in general (Lehman Et al., 20020; Fachini Et al., 2012).

Peansupap and Walker noted that when considering innovation diffusion in the context of digital media, managerial assessment isn't an accurate indicator without the inclusion of factors that focus on the digital media technology itself. These factors are motivation for usage, training, technical support, supervisor support, and open discussions (Peansupap & Walker, 2005).

Additional studies developed an even more confined evaluation criteria specific to the architecture and building production field; The developed assessment models measure the e-readiness of an organization to adopt digital media innovations. The two main models

are VERICT (Ruikar Et al., 2006), which focuses on the building production aspect, and BEACON (Khalfan & Anumba, 2006), focusing on the engineering aspect. Both models are extremely similar in assessment criteria, with the only difference being VERDICT including management as a factor, while BEACON has a different approach of placing importance on the project itself. The other three shared assessment criteria are people, processes, and technology.

Diffusion of Digital Media in General Contexts

The process of diffusion has different intricacies based on the contexts it is applied to. As stated earlier, there are numerous social, technical, and managerial factors that shape how the diffusion process occurs after the initial adoption phase. The impact of each factor differs between different scenarios of adoption. For digital media technologies, Newell proved that the diffusion process is primarily influenced by spreading socio-technical beliefs like knowledge and ideas rather than the sharing of digital media artifacts (Newell Et al., 2000). This finding is further emphasizing older established presumptions by Reddy, stating that effective communication between digital media technologies' manufacturers/developers, relevant supportive sectors, and nonmarket sectors positively influences the adoption and diffusion processes (Reddy Et al., 1991). Although this approach is preferred, McCorkle argues that it is plagued by the shortcomings of budget limitations, insufficient time, and the unavailability of specialized technical support (McCorkle Et al., 2001); Though they suggested that the effects of these drawbacks can be limited by relying on technology champions to enhance digital media diffusion internally throughout the diffusion process (McCorkle Et al., 2001).

Digital media diffusion is driven by the computability of the digital media technology within the context, while Zhu argues that security concerns eclipse added costs when considering any hindrances (Zhu Et al., 2006). Furthermore, competitive climate significantly influences the diffusion of digital media technologies, as it represents the context of the industry which guides various diffusion activities in organizations (Zhu Et al., 2006; Robertson Et al., 1986). Finally, it is worth noting that Vargo's research in digital media diffusion proposes a completely different theoretical framework, where the focus of the diffusion process is on a recursive service-focused ecosystem of diffusion processes instead of focusing on technological or market aspects (Vargo Et al., 2020).

Diffusion of Digital Media in Architecture

According to MacVaugh, in the architecture and building production sector, diffusion of digital media technologies is influenced by the social, technological, and knowledge acquisition conditions of the context regardless of its scale (MacVaugh Et al., 2010). These diffusion processes are prompted by comparative acquired advantage considerations, where early adopters are comprised of highly skilled entrepreneurs (Tudományok, 2010; Geroski, 2000; Yoav Et al., 1973) who have the technological prowess of employing these advanced technologies without guidance. This is why Attewell states that firms tend to delay adoption of digital media technologies until sufficient information and services are available to lower the existing knowledge barriers (Attewell, 1992). Regardless of the time of adoption, Shibeika established three phases that diffusion occurs through in firms within the architecture and building production field. Namely technology management centralization, digital working practices standardization, and digital resources' globalization (Shibeika Et al, 2015).

Shibeika noted that the diffusion process isn't straightforward, as a mixture of partial diffusions occur simultaneously throughout the organization until complete adoption is reached (Shibeika Et al, 2015); But according to Bohlmann this can be sped up through effective internal and external cross-segment communications within the industry, which requires immense collaborative efforts (Bohlmann Et al., 2010).

2.4.3 Benefits and Barriers within the Context of Architecture

According to Ng, The adoption of digital media has some major systematic prerequisites needed to allow for an efficient and useful integration (Ng Et al., 2022). As the availability of these prerequisites is usually dependent on conscious efforts to invest in these technologies, it is expected that there will be barriers of adoption in some cases. Throughout literature, any requirement can be a barrier of adoption depending on the different contexts considered.

Not all barriers are related to technical requirements, as it has been shown that socioeconomic factors play a significant role in the adoption of digital media. For instance, Akdag and Maqsood stated that countries with lower income tend to struggle with the adoption of digital media; citing financial costs, lack of the availability of complimentary services for digital media, negative unsupportive sentiments from clients, unavailability of skilled personnel for the adoption process, unwillingness to train or invest in education, and finally the main issue cited is that no intent of digital media adoption is present unless governmental guidelines mandates it (Akdag & Maqsood, 2019). In studies focusing on professional architecture and building production firms, different contexts were analyzed but the barriers remain similar regardless of the context. Furthermore, Soulikias criticized

digital media for being devoid of the qualitative qualities of architecture, where the locality and cultural aspects were sacrificed for speed and efficiency (Soulíkias Et al., 2021).

Kim highlighted that in areas where digital media is used for construction activities, the adoption process becomes very difficult due to the excessive costs, size limitations of machinery and storage, and the relevance of adopted digital media to current and future design activities (Kim Et al., 2021). Some additional barriers established by Suprun and Stewart are summarized below (Suprun & Stewart, 2015):

- Economical aspects:
 - Increased design product cost.
 - Risky economic investment.
 - Long-term investment, with high initial costs.
- Regulatory limitations:
 - Restrictive nature of governmental legislation.
 - Inefficient tendering process if not widely adopted in the market.
 - Regulatory codes (building codes, for example) aren't suited.
- Constant investment in research and development is required.
- The availability of information and tools needed for proper adoption.
- Lack of cooperation between stakeholders:
 - Fragmented nature of the professional industry
 - Varying levels of interest in adoption
- Client and developer attitudes:
 - Willingness of digital media adoption
 - Concerns regarding implementation

Tsai noted that the main responsibility of digital media adoption lies on managerial stakeholders and decision makers when considering a professional context (Tsai Et al., 2014); This is further supported by Wang and Song's findings, stating that managerial support is directly related to the satisfaction and willingness of adoption of users within organizations (Wang & Song, 2017). In conclusion, organizational support is deemed crucial for the overall success of digital media adoption (Chen Et al., 2019; Ahuja Et al., 2016; Won Et al., 2013).

Finally, Chaszar and Joyce crucially highlighted that some barriers are self-inflicted due to the nature of digital media. As some limitations need to be introduced to make the technologies more accessible. These constraints are introduced by the creators of any digital media technology, then become limitations added to future design products produced (Chaszar & Joyce, 2016).

2.5 Digital Media Applications in the Saudi Architecture Market

The usage of digital media is a widely discussed topic in Saudi Arabia. With the Kingdom's approach towards innovation and technology adoption, a slew of studies were done targeting different sectors of the industry. Unfortunately, minimal focus was given to the architecture and building production field, and even less was done focusing on the architectural design process. Hence, in this section the study will focus on studies that cover areas that are in accordance with topics relevant to the study; Such an approach in assessing literature is adopted to overcome the lack of exactly similar studies available, ultimately allowing the representation of developments in the architecture and building production sector within Saudi Arabia.

2.5.1 Design Process Advancements

The architectural design process has seen some attempts of elevation within literature focused on Saudi Arabia. Those studies focusing on the design process aim at achieving a particular goal of having an added benefit to accompany the final design product. These efforts don't particularly improve the architectural design process itself, but they broaden its reach using digital media.

For instance, Abdulmajeed's studies within the residential building production sector showed that mass customization is a hot topic that greatly affects the design process. In its simplest form, mass customization allows for each individual homeowner to provide feedback for their home's designs prior to their construction, i.e. within the design process. Mass customization can be enabled within the architectural design process by utilizing digital media, especially parametric design, and integrating it within the workflow of the project (Abdulmajeed et al., 2022).

Another aspect that heavily affects the architectural design process is the various types of building performance assessments. These are measurements that simulate and predict how the performance of a building measures based on different criteria. Each criterion to be assessed requires some modifications to the architectural design process to accommodate its requirements. Ahmed stated that the most prominent examples within the Saudi architecture and building production field include the usage of building energy modelling and simulation throughout the design process to improve sustainability (Ahmed et al., 2017) and energy efficiency (Ahmed et al., 2019).

2.5.2 Information and Communication Advancements

Effective documentation is essential for an efficient architectural design process, and in turn successful progression into tendering and procurement. In fact, Flentje stated that inadequate documentation is the leading factor in sabotaging the tendering process (Flentje Et al., 2014). In an attempt at recognizing these issues, digital media was used to them by ensuring that data is appropriately available and stored throughout the project, which is in line with the Kingdom's approach of using technologies to automatically solve problems without needing to invest in manpower to satisfy redundant tasks. This has been achieved through the development of E-tendering models which were specifically designed to fit the needs of the Saudi architecture and building production field. The adoption of E-tendering in the Saudi Arabian market has allowed for easy switching to an integrated design process where contractors are included throughout the architectural design process and are part of the decision-making process; Al-Yahya stated that the main aim is to minimize the time taken for the architectural design process to reach the construction phase, improve the quality of the tendering process, and to finally maximize the transparency of the entire process (Al-Yahya Et al., 2018). E-tendering is heavily reliant on the availability of data, which is why it is usually accompanied by BIM technologies for maximum efficiency. In fact, Majzoub observed that the integration of BIM into E-tendering in the Saudi architecture and building production field has been directly responsible for a 9.42% and 5.5% increased likelihood in tender winning probability in terms of quality-based selection and cost-based selection respectively (Majzoub Et al., 2021).

Literature shows that BIM technologies are rapidly increasing in usage within the Saudi architecture and building production sector. Several studies analyzed the Saudi industry to

assess its readiness and willingness to adopt BIM. Despite the various advantages of adopting BIM, Aljobaly pointed out that the industry is reluctant in the adoption process as it requires many systematic changes to be made (Aljobaly Et al., 2020) which require both time and funds. Additionally, Almontaser noticed that stakeholders lack interest in any form of adoption. This combined with the lack of required experience for an adequate adoption process were major caveats in the path of BIM in the industry (Almontaser Et al., 2018).

2.6 Literature Review Conclusion

An extensive literature review on several related topics was conducted. This literature comes from a variety of fields and covers a wide area of topics related to digital media technologies and their application in professional practice in architecture design and construction phases. Data gathered through this literature review is crucial for the subsequent phases of the research, particularly building the questionnaire survey. This data also provides the theoretical background and foundational framework that will guide the work during the whole study.

The systematic literature review has covered a wide range of topics that can be grouped under three main categories: 1) Types of digital media and software used in the architecture and building production, 2) Architecture design and related activities, 3) Range of stakeholders involved in the architectural design and building production activities. Below is a summary of the findings in these three areas:

- **Types of Digital media technologies used in architecture and building production.** The literature review has revealed a range of prominent digital

media and information technology that are used in architectural practices worldwide as well as in Saudi Arabia and the region. Existing research shows that there are a wide range of digital media in use in the architecture and building industry, and these tools are distributed among a wide range of application brackets that can be summarized as follows:

Table 1: Digital Media Technologies

Technology	Applications
Image Processing and Digital Drawing	Photoshop, Illustrator, Inkscape.
2D + 3D drawing and modeling (CAD)	AutoCAD, SketchUp, SolidWorks.
Building Information Modelling (BIM)	Revit, ArchiCAD, Navisworks.
Parametric Design Tools	Rhino (grasshopper), Fusion 360, Creo.
Big Data Tools	MongoDB, Tableau, Apache Hadoop.
Machine Learning + Artificial Intelligence	ChatGPT, Amazon Alexa, Google Cloud Machine Learning Engine, Azure Machine Learning Studio.
Technical Simulations	Revit, Computational fluid dynamics, Design Builder, Fusion 360, MATLAB.

- **Phases of architectural Design and related Activities.** Review of the literature revealed a range of design and other work activities in the architecture design and construction field. This includes all design and related work that spans various work phases from the predesign phase up to construction and as-built drawing phase. The review identified types of design and related activities, information content involved in the activity, the digital media supporting these activities and the usage patterns of these media. The phases of the architecture and building production design process and prominent technologies in them are:

Table 2: Prominent digital media technologies in different design phases / activities

Design Phase / Activity	Prominent Digital Media Technology
Predesign Phase	Technical Simulations
Preliminary Design Analysis Phase	-
Conceptual Design Phase	Machine Learning + Artificial Intelligence
Schematic Design Phase	Building Information Modelling
Design Development Phase	Machine Learning + Artificial Intelligence, Parametric Design Tools, Big Data Tools

Presentation Phase	Image Processing and Digital Drawing, Technical Simulations
Documentation Phase	Machine Learning + Artificial Intelligence, 2D + 3D drawings and modelling, Building Information Modelling, Big Data Tools
Construction Phase	Building Information Modelling, Big Data Tools

- **Stakeholders involved in architectural design and building production.**

Literature reviewed shows a range of stakeholders involved in the architectural design and building production activities. The review of existing literature showed that the architecture and building industry is highly fragmented and several stakeholders are involved within specific tasks in the building design and production process. Although the type of stakeholders involved and nature of their involvement may vary across different types of projects as well as across regions and countries, the following stakeholders are found in most of the projects, whether the project is in Saudi Arabia or somewhere else:

- Clients
- Architects
- Engineers
- Consultants
- Contractors

- Commissioning Agents
- Building Managers
- Regulatory Bodies

Finally, the following aspects were examined throughout the literature review without being under one specific heading/subheading:

- Design activities and the workflow in these processes.
- Information Flow across various phases/activities.
- Usage patterns of digital media.
- Digital Media Innovation Adoption and Diffusion.

CHAPTER 3

Research Methodology

This study aims to assess the level of adoption and usage patterns of digital media (i.e., applications, computing resources, and information technology) in the architecture and building production sector in the Kingdom of Saudi Arabia. The development of a reliable methodology to collect relevant data is a cornerstone for the study. The literature review chapter collected and analyzed secondary data to contextualize the study including highlighting relevant methodologies used in existing literature in this area. This chapter describes in detail the methodology developed and adopted to conduct this research.

3.1 Methodology Overview

The study can be described as correlational in nature. Due to the nature of the study and the methods used to assess the factors considered, an experimental research method is not practical and will not lead to generalizable findings. Each method contains theoretical biases and has their limitations if used separately. Multi-method research approaches are an improvement over single method approaches as they allow researchers to examine consistency in the results and thereby increase confidence in the findings (Creswell 2013; Tashakkori & Teddlie, 1998). The use of multiple methods allows the researcher to check the consistency of the data collected thus increasing the reliability and validity of the results. Furthermore, it enables cross-validation and thus increases the accuracy of the data and findings. The multi-method approach contributes to a better understanding of the research problem. For instance, Jogulu pointed out that using multi-methods in research

strengthens findings to allow for deeper understanding of social phenomena (Jogulu Et al., 2011). Turner Et al (2017) expanded on Jogulu's findings, stating that the usage of multi-methods mitigates the limitations of each individual method. Furthermore, Almeida (2018) highlighted that using a multi-method approach provides a broader more comprehensive vision of research problems. Finally, it is worth noting that multi-method approaches enable the triangulation of methods, which states that both qualitative and quantitative methods are complementarily used rather than competitively (Jick Et al., 1979).

Examining the usage of digital media and its support for the range of design activities across a range of stakeholders is a complex phenomenon and thus requires multiple research methods to ensure the reliability of the data collected. To increase both the validity and reliability of the research, the study uses the following research methods: 1) literature review, 2) questionnaire survey and 3) in-depth interviews. The literature review is used to identify the design activities in the architectural design process, range of digital media usage in those activities, and the sentiments of stakeholders towards the range of usage. The questionnaire survey is used to collect a wide range of quantitative data from practitioners in the Saudi architecture and building production field, while interview surveys are used to acquire in-depth, focused qualitative information on some aspects of the research problem.

Mixed-methods research design focuses on combining two or more different research approaches based on the types of data (Tashakkori and Teddlie, 1998). The questionnaire mainly collects quantitative data, while the interview surveys collect qualitative data, and literature review deals with both qualitative and quantitative data. Qualitative data and quantitative data each have their own bias and limitation if used separately. Using both

types of data is an improvement over a single approach. Such a hybrid approach (i.e mixed methods) is highly recommended in architectural research as it enables better understanding of complex phenomena through cross-validation and converging of evidence (Love et al., 2002; Winch et al., 1998). As such the study employs multiple methods, multiple data types (quantitative and qualitative), and multiple measures (rating scale, coding of design activities, ordering according to criteria, coding of digital media technologies, etc). Such an approach enables cross validation of the results and strengthens the study theoretically and methodologically. Figure 2 shows an outline of the adopted methodology including methods used in each phase and the different phases of the methodology mapped to the research objectives.

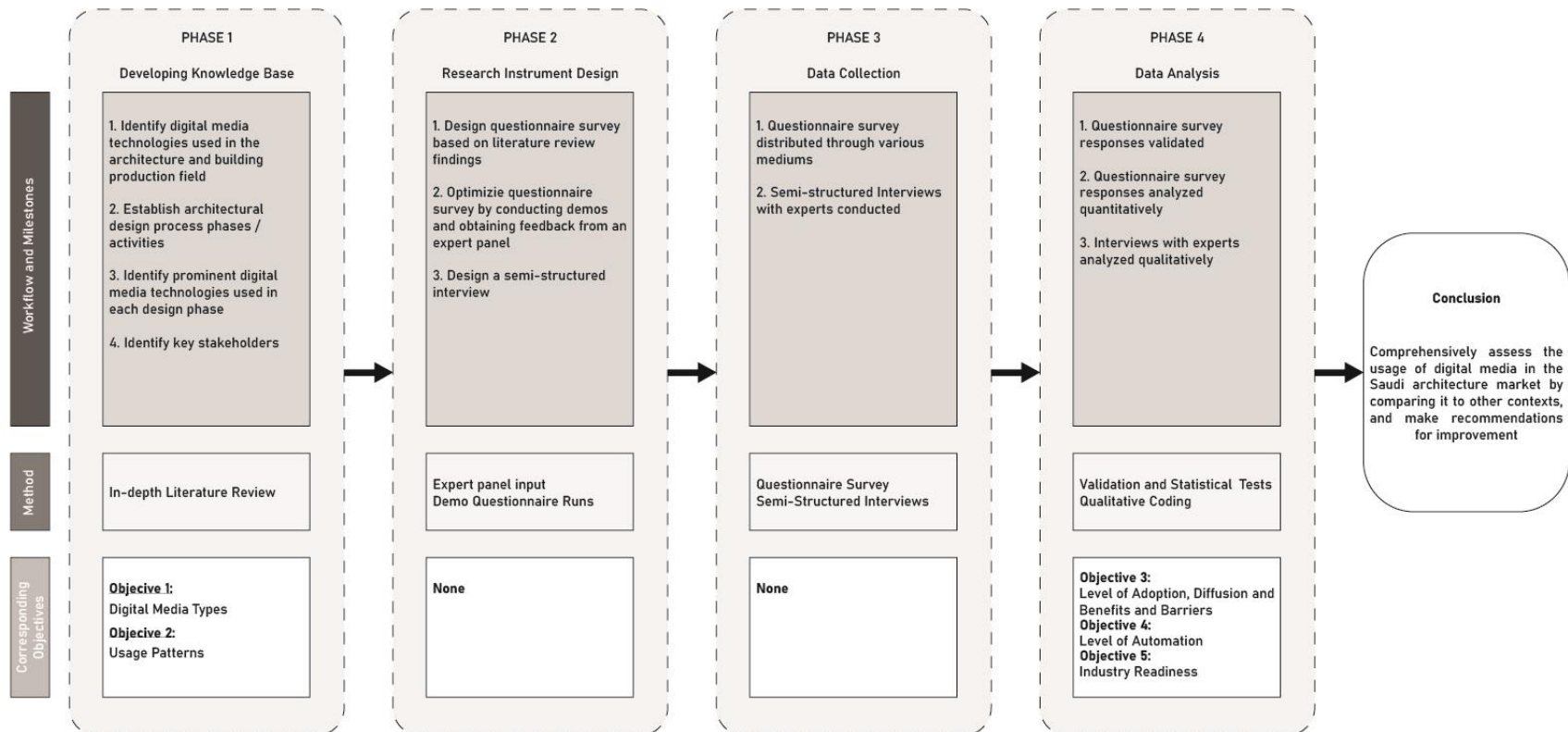


Figure 2: Theoretical Framework of Methodology

3.2 Research Methods

The following is a detailed discussion of the three research methods used: 1) literature review, 2) questionnaire survey and 3) in-depth interviews.

3.2.1 Systematic Literature Review: Architectural Design Activities and Digital Media Types

The literature review aims to identify and establish the following three core information sets: 1) major categories of digital media technologies used in architectural design and construction, 2) major activities in architectural design & construction, 3) categories of stakeholders involved in architectural design and building production. This information is essential to identify and establish before building the questionnaire survey as it represents the major variables and factors in the study. This data was collected through a systematic literature review as detailed and discussed in sections 2.1 and 2.2 of chapter 2 of the thesis. A summary of the main phases of the architecture and building production design process and the types of digital media technologies is presented in section 2.6.

3.2.2 Questionnaire Survey

Design of the Questionnaire Survey

A structured questionnaire is one of the most used methods to collect primary data in research studies as it enables researchers to collect a wide range of quantitative data in a short time. This study developed and used an online questionnaire survey to collect data from respondents as it improves reach and response rate.

The questionnaire survey aimed to gather data related to digital media use and the diffusion level of each digital media technology in the architecture and building production sector in Saudi Arabia. One online survey form was used to collect data from all participants.

The used questionnaire consists of two types of questions: questions using the 7-point bipolar rating scale (i.e. Likert-scale) and open-ended questions. The survey consists of a total of 27 questions (see Appendix A). 22 questions are Likert-scale questions while 5 questions are open-ended. 3 of the Likert-scale questions have an open-ended question appended to them, while another 3 are continued through other questions.

The survey questions consist of four types of questions. The first group (Q1-Q7) collects demographic data about the participants that focuses on portraying the respondents' profile in a manner that is relevant to the study, the second group (Q8-Q14) covers the usage of digital media technologies across design/work activities, group three (Q15-Q21) addresses the topic of automation in addition to the readiness of the Saudi market for digital media technologies, and the fourth group (Q22-Q26) covers the state of digital media technologies' diffusion and adoption within the Saudi architecture and building production field.

Table 3 provides a summary of the questions, their type, their group, and their connection to the objectives of the study. The questions in the table are simplified forms of the questions. The full questionnaire is available in appendix A.

Table 3: Questionnaire survey's questions grouped and mapped to research objectives.

No.	Question (simplified)	Obj 1	Obj 2	Obj 3	Obj 4	Obj 5	Question Type	Group
1	Name of firm/organization?	Demographic Data					Open-ended	G1
2	Number of employees?	Demographic Data					Multiple choice	G1
3	License type?	Demographic Data					Multiple choice	G1
4	Main type of work?	Demographic Data					Multiple choice	G1
5	Your profession?	Demographic Data					Checkbox	G1
6	Years of experience?	Demographic Data					Multiple choice	G1
7	Role in decision-making?	Demographic Data					Multiple choice	G1
8*	Familiarity with digital media technologies?	✓		✓			Likert-Scale	G2
9*	Usage extent of digital media technologies?	✓		✓			Likert-Scale	G2
10	Rank digital media based on usage?	✓		✓			Ranking	G2
11	Most used digital media in design activities?	✓	✓	✓			Open-ended	G2
12	Work conducted digital media?	✓	✓	✓			Rating Scale	G2
13	Reasons for underutilization of digital media?		✓	✓		✓	Checkbox	G2
14	Reasons for utilization of digital media?		✓	✓		✓	Checkbox	G2
15	Perceived work activities automation?		✓	✓	✓	✓	Rating Scale	G3
16	Factors affecting readiness for automation?		✓	✓	✓	✓	Checkbox	G3
17	Actual level automation?		✓	✓	✓	✓	Rating Scale	G3
18	Satisfaction with work automation?		✓		✓	✓	Likert-Scale	G3
19	Factors driving digital media adoption?			✓		✓	Checkbox	G3
20	Factors hindering digital media adoption?			✓		✓	Checkbox	G3
21	Stakeholders support of digital media adoption?		✓			✓	Likert-Scale	G3
22	Agreement with the following statements?		✓	✓		✓	Likert-Scale	G4
23	Digital media to be adopted in 2-4 years?			✓		✓	Open-ended	G4
24	Digital media that was adopted in 2-4 years?	✓		✓			Open-ended	G4
25	Digital media adopted before 5 years?	✓		✓			Open-ended	G4
26	Training provided?	✓	✓			✓	Open-ended	G4
27	Extra feedback (optional)	✓					Open-ended	all

Design Criteria

Three considerations were taken to ensure maximum coverage of topics with minimal number of questions. Firstly, an integrated approach was adopted to ensure that questions cover multiple objectives to enable horizontal exploration of examined issues between questions. Secondly, Likert-Scale questions were used to acquire intensive data on crucial areas of the study; Thus, further helping in the horizontal exploration of issues in addition to allowing more effective vertical analysis. Data analysis is explained in more detail below. Finally, interviews are used to allow for further in-depth exploration of various areas that aren't adequately covered by the questionnaire survey. Since the interviews are more open-ended, they can flexibly cover any areas while simultaneously allowing for in-depth exploration of issues based on the interviewees' expertise.

To collect reliable and valid data the questionnaire design should follow a range of specific criteria. For instance, the following design criteria is adopted from Dillman (2011) during the questionnaire design:

- Appropriate language usage.
- Simple and short questionnaire.
- Using the layout, structure, order of questions, and graphics to make an interesting and easily completable questionnaire.
- An introductory statement explaining the study and signifying the role of the participant.
- Using incentives to encourage participation.
- Convenience of participation.

In addition to the aforementioned criteria, two recommendations were adopted from literature specifically focused on designing questionnaires for analyzing organizational contexts (Schneider and Reichers, 1983; Payne, 1990) with minor adjustments to fit the study.

- Climate not structure: Though overlapping, the questions need to be focused on the climate of adopting digital technologies, instead of the structural intricacies of organizations.
- Description not evaluation: Questions must help describe personal opinions in a way that facilitates conclusions and evaluations to be made. Participants should only provide data that facilitates answering the intended research questions and the intended research objectives.

Cross Referencing and Comparisons

To have critical and useful data for analysis, the study incorporated components of relevant well-known surveys found in literature. Such approach will enable the study to have meaningful information that enable the comparison of the examined phenomenon (i.e., diffusion of digital media technologies in the Saudi Arabian market) with those of other countries, particularly developed and similar countries (Abrishami Et al., 2014; Chen Et al., 2019; Mollaoglu Et al., 2016; Suprun & Stewart, 2015; Panuwatwanich & Stewart, 2012). For instance, some parts of the adopted questionnaire survey are aligned with the “IT Barometer Survey” which is a survey designed to assess the usage of digital media in a range of developed and undeveloped countries by assessing their external and internal capacities of adoption (Technology, 2016; Samuelson, 2002). This will result in more

useful data that enables better examination of the performance of the Saudi Arabian market compared with that of other nations.

Experts Review of the Questionnaire Survey

After designing the questionnaire, and prior to pilot testing, the questionnaire survey was evaluated using a panel of experts. The panel consists of four professionals, three from academia and one industry professional. The panel was briefed about the study and its objectives, then they were asked to provide feedback on the survey for improvement. The Question Appraisal System (Willis and Lessler, 1999) was adopted in the experts' evaluation process. The expert review focused on the following issues:

- Clarity of the questions themselves and their intents from the participants' point of view.
- Questionnaire instructions and their understandability from the participants' point of view.
- Issues with retaining relevant knowledge throughout the questionnaire.
- Problems with assumptions and their logic.
- Avoidance of biases.

After the experts' review phase, an initial refinement of the survey is done based on their feedback. After this phase the pilot test was conducted to double-check the appropriateness of the questionnaire survey before fully distributing it to participants.

Pilot Testing

A pilot test was conducted to check the appropriateness of the questionnaire survey before distributing it to participants. The pilot run was conducted during the period of August 10th to the 30th of the same month of the year 2022. Ten participants partook in the pilot test. The test run was to evaluate the survey questionnaire and collect the participants' feedback on the survey itself, particularly the understandability of questions and answers, as well as the content of the survey and its completeness, as done in the experts review stage. This information is used to further develop and refine the questionnaire (Sekaran, 2003; Cavana et al., 2001). Those who participated in the pilot testing were excluded from participating in the real/actual run of the survey, as they can't appropriately fill the questionnaire again without bias.

Questionnaire Refinement

Based on the experts review and the pilot testing, some refinements and improvements were made to the questionnaire. For instance, the draft was deemed too long and thus could be exhausting to participants, while the questions ranged from extremely simple to extremely detailed which was a great hindrance to the flow of the survey. Additionally, the explanations of the concepts discussed covered in the questionnaire were too long while only some of the respondents read the entire instructions. The professionals expressed similar opinions, citing the exhaustive nature of the long and detailed questions and the explanations as major weaknesses. Additionally, redundancy and overlapping between some concepts were identified between some questions. In conclusion, the edits resulted in reducing the number of questions from 41 to 27, while simplifying them to focus on their

descriptive capabilities instead of their evaluative ones. Furthermore, conceptually repetitive and overlapping questions were avoided. This was done as common-method variance produces major confounding effects, which are considerable threats to the validity of survey-based research (Podsakoff and Organ, 1986). Additionally, the explanations were removed and instead, examples of digital media tools or applications were used as they proved to be a better way of describing digital media technologies.

3.2.3 Participants and Sample Size

Stratified random sampling (i.e. judgmental sampling) is used alongside convenience sampling because they are more efficient in collecting data from distinctly characterized individuals (Sekaran & Bougie, 2003). Invitation to participate is done through emails that include a link to the survey. Participation is restricted to individuals contacted. The questionnaire survey is directed towards professional practitioners affiliated with engineering and architectural design firms within Saudi Arabia. Valid participants are expected to have the following characteristics:

- Currently working or have worked in the architecture and building construction field in Saudi Arabia for at least a year.
- Architects or engineers working in architectural design firms, consultants, and/or contractors.
- At least 5 years of experience in architecture or closely related fields.
- Have fair experience in using digital media in their daily work.

The population of the study is architects and other professionals in the architecture and construction field. Contacting the Saudi Engineers Council, no clear data regarding the

population size is available. Hence, an acceptable range of population was adopted in accordance with similar studies from literature. The range is between 60 and 120 participants. A minimum of 30 participants are needed for a statistically accepted data set, which is well within the established range.

3.2.4 Questionnaire Distribution and Data Collection

An online survey was used to collect the data. The questionnaire was written using the SurveyMonkey platform. Links to the survey site were sent to participants and they could access it using computers, laptops, or mobile phones. Invitations to participate in the survey were sent via email by contacting various firms within the kingdom. Direct WhatsApp messages were also used to contact firms/offices in case emails weren't suitable. In addition, well-known architects and high-ranking professionals were directly contacted over the phone. All ranges of architectural offices in the Kingdom were targeted, which are officially categorized into five groups:

- Engineer Office.
- Consultant Engineer Office.
- Engineering Consultations Office.
- Engineering support service offices.
- Professional engineering companies.

The same questionnaire survey was sent to all firms/offices. To avoid any overrepresentation of a smaller sample, no more than three randomly chosen participants were considered from the same professional office.

A total of approximately 500 surveys were distributed. Data was collected between 15th December 2022 and 15th April 2024. Responses were received from 116 participants. Data from all respondents was analyzed after excluding any improper responses and ensuring that no one particular office was overrepresented.

3.2.5 Variables and Measurements

The study focuses on studying the relationship between several variables. These variables are related to the research questions and its objectives which are outlines as follows:

- Which digital media technologies are used in various stages of the architectural design process and related work.
- Which design and other related activities are supported by which digital media.
- The difficulties faced and the barriers that hinder the adoption of these technologies.
- The benefits gained from adopting these technologies as perceived by the users in practice.
- Any opportunities seen by practitioners regarding new technologies to adopt.

As such the study examines five main variables; Three predictor/independent variables (occasionally referred to as factors) and two outcome/dependent variables as detailed below:

Predictors/independent variables:

- Participants' characteristics (demographic data)
- Architectural design & related/supporting activities.
- Categories of stakeholders involved in architectural design and supportive activities.

Outcomes/dependent variables:

- Types of digital media technologies used in architecture and building production (dependent variable).
- Participants' preference and perception regarding digital media use, difficulties/barriers, benefits gained, etc. (dependent variable)

Table 4 provides a summary of the variables, their types, and their method of measurement. Interviews cover all variables, while capitalizing on their semi-structured nature to focus on less represented variables like stakeholders' involvement. Architectural design and related activities can be used as both dependent and independent variables based on the analysis approach. When each activity is assessed in isolation from the rest, they are independent. While the variables are dependent when they are all analyzed together categorically.

Table 4: Variables of the study.

Variable Name	Variable Type	Measurement Type & Level	Measured in Questions #
Participants' characteristics (demographic data)	Predictor (Independent)	Categorical Variable	1, 2, 3, 4, 5, 6, 7
Types of digital media technologies used	Outcome (Dependent)	Categorical Variable. 8 levels	8, 9, 10, 11, 15, 17, 23, 24, 25
Architectural design & related activities	Predictor (Independent)	Categorical Variable. 8 levels	11, 12, 15, 17

Stakeholders involved	Predictor (Independent)	Categorical Variable. 8 levels	18, 21
Participants preferences and perceptions	Outcome (Dependent)	Ratio Variable	12, 13, 14, 15, 16, 19, 20, 22, 26, 27

3.2.6 Interviews

Semi-structured interviews are used as a method to acquire in-depth data on issues and topics that need further exploration. A convenient sample of the questionnaire respondents was selected for the interview. Potential participants for the interview were identified through the questionnaire and later contacted and followed up by phone and/or email. The interviews commenced after an initial analysis of the responses to the questionnaires, which aided in probing relevant contextual topics that are worth further investigation. The interview questions were built around selected issues in the questionnaire survey and focused on obtaining a deep understanding of some relevant issues identified in the questionnaire survey.

The semi-structured questions of the interview are consistent with the questionnaires' approaches and procedures but focus on gaining detailed insights in particular areas based on the interviewee's experiences. Thus, the interviews' data are considered complementary to that of the questionnaire.

Five professionals with varying experiences were interviewed from the Saudi architecture and building production field. Three interviewees were small to medium architectural firm owners, while two were highly experienced employees undertaking executive positions in large firms.

3.3 Analysis of Data

As a result of the complexity of the phenomenon being studied and the different data types that were collected, both quantitative and qualitative methods were used to analyze the data. The approaches used to analyze the collected data are described below.

3.3.1 Questionnaire Quantitative Data

The questions of the questionnaire survey, particularly rating scale questions, are analyzed using a range of statistical methods that are described in detail below.

Single-factor ANOVA was performed on questionnaire data to test if participants opinions and preferences with different digital media are affected by some variables such as experience or type of firm.

Descriptive statistics, namely mean, mode, median, and interquartile range, were used to represent large sets of data into simple values to easily identify patterns and consensuses. Additionally, comparisons between the effects of independent variables on dependent variables can be easily tested.

Chi-squared tests were used to investigate if there is a dependency between different combinations of variables. Its usage determines whether any combination of two variables influences the data set's statistics. Karl Pearson's Chi-square test (Appendix B, formula 2) was used as the study's sample size falls well within the recommended sample size for usage, which is recommended to be a minimum of fifty (Turhan, 2020).

Correlation tests were conducted to investigate whether there is a correlation relationship between two variables. Due to the indiscriminate nature of the study's variables, i.e. no relationship between variables can be confidently predicted, Pearson's correlation

coefficient was used (Sedgwick, 2012). Specifically, the Sample Correlation Coefficient was used for the study's population (Appendix B, Formula 3). As it uses standard deviation, it is a normalized measurement where all values lie between -1 and 1.

Consensus tests were used to examine if there are consensuses on some issues such as the extent of usage of particular technologies within one design phase or identifying the most prevalent barriers to the adoption of digital media. This is done primarily using descriptive statistics such as mean, mode, median, and standard deviation. Although enough for vertical isolated instances, extra analysis may be needed for horizontal relationships.

Multivariate analysis was used in analyzing most data collected by the questionnaire surveys, as it is the most common approach in such studies. Similar studies focusing on organizational climate within the field of management research in terms of the diffusion of innovation (Patterson et al., 2005) found it most effective in unanimity.

It is important to acknowledge that the discovery and analysis of typical casual relationships require the conscious manipulation of different variables. However, in studies where a behavioral phenomenon is being considered, such a setting is unlikely to exist (Podsakoff and Organ, 1986).

It is important to note that the study's framework is structured around the variables established to accomplish the study's objectives. These variables are constant throughout the study, while their interconnected relationships are to be analyzed. A visual representation of the relationship between objectives, variables, and the group they belong to can be seen in Table 5. Predictor and outcome variables represent independent and dependent variables respectively. Variables are adopted from table 4.

Table 5: Outline of Data Analysis for the Questionnaire Survey.

No.	Question (simplified)	Topic/issue examined	Variables	Research Objective
1	Name of firm/organization?	Demographic	Participants' Characteristics	-
2	Number of employees?	Demographic	Participants' Characteristics	-
3	License type?	Demographic	Participants' Characteristics	-
4	Main type of work?	Demographic	Participants' Characteristics	-
5	Your profession?	Demographic	Participants' Characteristics	-
6	Years of experience?	Demographic	Participants' Characteristics	-
7	Role in decision-making?	Demographic	Participants' Characteristics	-
8	Familiarity with digital media technologies?	Types	Types of digital media technologies used	1, 3
9	Usage extent of digital media technologies?	Types, Adoption	Types of digital media technologies used	1, 3
10	Rank digital media based on usage?	Types, Diffusion	Types of digital media technologies used	1, 3
11	Most used digital media in design activities?	Types, Patterns, Adoption	Architectural design & related activities; Types of digital media technologies used	1, 2, 3
12	Work conducted digital media?	Types, Patterns, Diffusion	Architectural design & related activities; Participants preferences and perceptions	1, 2, 3
13	Reasons for underutilization of digital media?	Patterns, Barriers	Participants preferences and perceptions	2, 3, 5
14	Reasons for utilization of digital media?	Patterns, Benefits	Participants preferences and perceptions	2, 3, 5
15	Perceived work activities automation?	Patterns, Automation, Readiness	Architectural design & related activities; Types of digital media technologies used, Participants preferences and perceptions	2, 3, 4, 5
16	Factors affecting readiness for automation?	Barriers, Automation, Readiness	Participants preferences and perceptions	2, 3, 4, 5
17	Actual level automation?	Patterns, Adoption, Automation, Readiness	Architectural design & related activities; Types of digital media technologies used	2, 3, 4, 5
18	Satisfaction with work automation?	Automation, Readiness	Stakeholders involved	2, 4, 5
19	Factors driving digital media adoption?	Benefits, Readiness	Participants preferences and perceptions	3, 5
20	Factors hindering digital media adoption?	Barriers, Readiness	Participants preferences and perceptions	3, 5
21	Stakeholders support of digital media adoption?	Readiness	Stakeholders involved	2, 5
22	Agreement with the following statements?	Barriers, Readiness	Participants preferences and perceptions	2, 3, 5

23	Digital media to be adopted in 2-4 years?	Diffusion, Readiness	Types of digital media technologies used	3, 5
24	Digital media that was adopted in 2-4 years?	Types, Adoption	Types of digital media technologies used	1, 3
25	Digital media adopted before 5 years?	Types, Adoption	Types of digital media technologies used	1, 3
26	Training provided?	Readiness	Participants preferences and perceptions	1, 2, 5
27	Open-ended question (optional)	all		

3.3.2 Variable Identification

In this study, factors refer to independent/predictors variables that affect the values or results of dependent/outcome variables. As shown in table 5 in accordance with tables 3 and 4, variables are divided into different groups based on the nature of the questions that they are derived from. These four groups are:

- Group 1: These factors are a combination of demographic data and context-related data. They cover personal identifying data of the individuals themselves and their relationships with their surroundings.
- Group 2: This category covers all information about technologies and their usage. These cover both software packages and technologies, in addition to the areas and extent of their use.
- Group 3: Factors relating to the automation of design activities lie under this category. Within the context of the study, automation means complete independence from human intervention and total reliance on technology.
- Group 4: Interpersonal information that relates to the effects of technologies and their adoption on individuals. These effects include internalized feelings and external sentiments towards technologies and their relative effects.

It is worth noting that only 13 variables were developed and are directly tied to single questions. This is because the selection criteria for factors were based on the perceived effectiveness of each question's impact on the remainder of the data when changed or manipulated. This was done to allow each variable to be assessed based on itself in relation to all the different data within the study. In simple terms, if trends can be found in the rest of the data by isolating different instances within the same question, then it is deemed worthy of establishing a variable. Theoretically speaking, every question in the questionnaire can become an independent variable by itself. However, many of those will be pointless as they add nothing outside of their isolated data set.

3.3.3 Representing Data

Representative data analysis refers to analytical methods and statistics used to describe and showcase the study's findings quantitatively. As the study focuses on deducting relationships and correlations between different factors, in addition to making deductions about the population of the study that directly satisfy the objectives, extensive raw data on its own doesn't satisfy those needs on its own as no proper questions can wholly cover any of the intended topics. Hence, multiple data analysis methods were adopted to showcase the findings through data in a concise quantifiable manner.

Multivariate Analysis

Contrary to conventional questionnaire survey-based studies, a method (like correlational analysis, for example) can't be used due to the inability to manipulate variables. Avoiding these constraints, multivariate analysis was used to quantitatively analyze the questionnaire survey's collected data. This analysis technique is most suitable due to its ability to

examine complex data sets with multiple dependent and independent variables (Tabachnick and Fidell, 2007). Multivariate analysis fulfills the following:

- Getting a simple general representation of the data.
- Discovering underlying relationships or correlations between factors.
- Provide a simple quantitative presentation of the data.

Descriptive Analysis

Descriptive analysis (also known as descriptive statistics) was used to obtain another form of a quantifiable simplified representation of the obtained data. Descriptive statistics are methods used to summarize and describe the main features of a dataset. Examples include measures of central tendency such as mean, median and mode.

This also helps in guiding the multivariate analysis, as it helps in determining if the data supports the hypotheses, in addition to easily assessing the validity of any assumptions. The outcomes of the descriptive data analysis, in addition to the statistics used, are as follows:

- Examining the profiles of respondents in relation to the population is done through percentage-based representation of identification (personal) data.
- Data screening is done by calculating the data's normality, standard deviation, means, and the standard errors of the means.
- A broad perception of the respondents' sentiments is acquired through preliminary analysis of the means of the data collected through the questionnaire survey.

It is important to note that both descriptive and multivariate analyses are done simultaneously, as their findings are complementary to each other. Simple explorations are usually done through descriptive analysis, whereas further in-depth explorations are done using multivariate analysis.

3.3.4 Questionnaire Qualitative Data Analysis

Data collected through interviews and other qualitative data collected by the questionnaire survey were analyzed using qualitative coding approaches (Skjott Linneberg & Korsgaard, 2019; Deterding & Waters, 2021). Qualitative coding is an integral part of qualitative data analysis and is essential in the decision-making process when realizing the findings of the study (Elliott, 2018). Due to the study's proposed methodology and its nature, the qualitative coding process is straightforward and directly adopts the objectives of the study. As the methodology adopts a sequential mixed method approach to collecting data, the study uses the findings from the first method (the questionnaire survey) to dictate the way the second method (interviews) is carried out. Though they are semi-structured interviews, they still follow the general gist of the study's findings through the questionnaire. This is important as it eases the process of mapping relevant information onto existing data.

Each objective is treated as a "category" when carrying out the qualitative coding process, and findings from the interviews are mapped to them. As the study's objectives are inherently interconnected, it is expected for data to be mapped onto multiple objectives. Additionally, as extra depth in replies is expected in interviews, an extra level of mapping is done by mapping data onto previously established factors. This helps data from both methods to be easily used in conjunction with each other; while adding depth to any findings relating to the factors.

It is worth noting that qualitative analysis provides a descriptive analysis of the various aspects being studied. As the questionnaire's findings were used to design the interviews, the findings are expected to be confined to being complimentary to the findings of the questionnaire. In addition to qualitative coding, representative data analysis methods like descriptive statistics were used to depict the data in a comprehensible manner.

3.3.5 Interview Data Analysis

Analysis of the semi-structured interviews follows a similar approach to the qualitative questionnaire data analysis. The interviews are transcribed, and the same qualitative coding approach used earlier in the questionnaire is adopted to map findings onto the objectives. As the discussions in the interview are open ended, the data collected from each interviewee varied in its content and topics discussed. By relying on keywords directly adopted from the objectives of the study (or their synonyms), the data collected from each interviewee is simplified to findings that directly relate to the study.

As these are experts' interviews, the number of interviews conducted is limited to only five. This is consistent with the intent of using them as supportive data for the questionnaire surveys, in addition to expanding on previous findings and probe for further details.

3.3.6 Cross-sectional Comparative Analysis

Comparative analysis is used to assess the relationships between the different data sets acquired. In advance of comparative analysis, all the interpretations of the data sets collected were self-confined, resulting in a limited scope of investigation. However, as the research's objectives are deeply intertwined which is reflected through the questionnaires' design and the number of objectives related to each question as seen in Table 3; it is essential to horizontally expand the analysis efforts by comparing the raw data of the

different sets in addition to analyzing any resultant relationships between multiple factors and variables within the study. Based on previously mentioned analysis methods, this can be effectively done through the implementation of multiple comparative analyses which fall under the following types:

- Horizontal Single Constant Factor: One factor is chosen as an identifier (not taking it into consideration within the analysis) and all other factors are analyzed in relation to it.
- Horizontal Multiple Constant Factors: More than one factor is excluded from the analysis, while the relationships between those excluded factors are used as identifiers.
- Confined Vertical Single Factor: This refers to analyzing data concerning a single factor to acquire an in-depth understanding of the sentiments around it. These are mainly used in questions with multiple Likert scales options.
- Multiple Vertical Factors: This takes a similar approach to the confined vertical single factor but uses in-depth data from multiple questions relating to different factors. This enables apothegmatic outlier relationships that don't clearly exist within the confines of established factors to be assessed.
- Horizontally Combined Relationships: Established relationships are compared in relation to other single factors or relationships. This allows the identification of trends in the data in accordance with the relationships that were discovered from the same data. Instead of comparing factors, the notion here is to examine any phenomena discovered and to assess whether other intrinsic findings can be found.

3.3.7 Data Reliability and Validity

Data reliability checks are used to ensure that data acquisition instruments were able to efficiently collect representative data of the targeted population. As there isn't any benchmarking reference for the expected results other than personal expectations and intuition, there exists no actual way of assessing the data's "correctness" in representing its context. Hence, reliability tests only consist of analyzing the data collected as a complete set and multiple smaller subsets to ensure the likelihood of them existing within a typical context. A complete set analysis looks at all the data collected, while the subsets will look at questions individually. This adds a layer of assurance to the validity of the data collected, as it ensures that each question's findings can exist independently of each other in isolation.

The survey's questions can be separated into two areas based on the type of data collected from the questions and the purpose of the questions themselves; Noting that questions of an open qualitative nature that probe the reasoning behind the answers to the qualitative questions don't require validation as they don't have established confines as the replies heavily depend on unique individual experiences. The two areas are Quantifiable Views (QV) and Reasoning (R).

Quantifiable Views (QV) questions include Likert-Scale questions and ranking questions that aim to provide quantifiable findings from the individuals' perspective. These provide the basis for raw conclusions with minimal direct reasoning from the respondents, relying on analytical approaches for conclusions to be made about relationships between factors. To validate this data, assessment of the instrument itself in addition to the data acquired is done. The statistical tests adopted for examining reliability are:

- Cronbach's Alpha: used on Likert-Scale type questions to measure the reliability of the scale used. It measures the internal consistency and the correlation level between data
- Analysis of Variance (ANOVA): used on the data set to ensure the homogeneity across the data collected, and to ensure that the collected data is likely to represent a single population which enables the generalization of assumptions within the context.

Reasoning (R) Questions are mainly of a multiple-choice nature with the option of adding extra feedback if the participant wishes to do so. They are supportive questions that are focused on elaborating on the feedback given and are inherently open-ended in nature. As they provide explanations to phenomena and aren't based on any quantifiable scale, they don't require validation as they will be used conjointly with QV questions to provide a broader perspective.

Finally, it is worth noting that questions of both kinds are designed with the intention of being complimentary to each other. No singular question can provide sufficient conclusions in isolation, as the context provided by analyzing them together is crucial for their relevance to the study's objectives. Hence, by validating the QV questions, R questions are indirectly validated.

3.3.8 Consensus Analysis

Feedback from the questionnaire survey and interview participants assesses the research objectives in relation to the Saudi architecture and building production field. The findings

acquired using various statistical analysis methods are analyzed to highlight whether consensus regarding various phenomenon exist.

Consensus of different aspects of the study are identified using descriptive statistical approaches, namely mean, mode, median, and interquartile range (IQR). Descriptive statistics are used to fully describe data sets, while the median and IQR are used to determine the consensus of the findings. The median is less sensitive to extreme values, making it more reliable for consensus identification instead of the mean. (Hsu Et al., 2007). The IQR represents the absolute difference (positive value) between the 75th and the 25th percentiles. It is considered to be a direct measure of consensus, where lower values represent higher degrees of agreement (Hsu Et al., 2007; Rayens Et al., 2000).

For each data set analyzed, consensus is identified in addition to the level of agreement of the study participants with the consensus. Consensus analysis is conducted to all data sets analyzed. Additionally, consensus found are used to direct the interviews to relevant discussions. Finally, consensus from the interviews are assessed based on the agreement between participants instead of the usage of statistics. This is because the number of interviewees is much lower than the questionnaire participants so they can be directly compared with one another, in addition to being compared to the findings from the questionnaire survey to establish absolute consensus.

CHAPTER 4

Data Analysis & Results

This chapter presents the results of the statistical analysis of the collected data. In addition to characteristics of the sample used, the chapter presents results related to data reliability, digital media use in the Saudi market, usage patterns of digital media across different phases of the architecture design and building production processes, level of digital media diffusion, readiness of the Saudi architecture and building production industry, various qualitative findings throughout the study, and finally the satisfaction with digital media.

4.1 Sample Characteristics

The study collected data related to six factors to describe the data set demographically. These factors are number of employees in the firm/organization, organization's license type, main field of work, profession of participant, experience of participant, and finally the participant's decision-making role within the organization. Table 7 represents the data's demographic profile.

Table 6: Demographic Data

	<i>Number</i>	<i>Percentage (%)</i>
Number of Employees in Firm		
Under 10	27	23
11-50	33	28
51-100	18	16
101-200	5	4
201-500	6	5
501-100	4	4
Over 1000	23	20
Firm License Type		
Engineer Office	36	31
Consultant Engineer Office	30	26
Engineering Consultations Office	25	21
Engineering support service offices	8	7
Professional engineering companies	17	15
Main Area of Work		
Architecture (design + consultation)	46	40
Engineering (design + consultation)	47	40
Construction	20	17
Project management	39	33
Participants' Profession		
Engineer	30	26

Architect	35	30
Building-related designer	22	19
Technical assistant	29	25
Participants' Experience in KSA		
Under 5	61	53
6-10	22	19
11-20	14	12
21-30	11	9
Over 30	8	7
Participants' Role in Decision-Making		
Owner / Partner	29	25
Employee with no administrative or decision-making role	76	66
Other	11	9

Firm Size Based on the Number of Employees

Table 6 shows the distribution of the questionnaire participants based on the size of the firm they work in. The metric used to measure the size of the firm was the number of employees. It can be seen from the table that firms with 11-50 employees are the most represented in the study comprising of 28% (n=33) of the study participants, followed by firms that have less than 10 employees at 23% (n=27), and finally followed by firms that have more than a thousand employees at 20% (n=23). The fourth and last majorly

represented firm size is in the range of 51-100 employees, at 16% (n=18). The data shows that small and large sized firms are properly represented by the data, while firms that fall in the medium range are minorly present in the data.

Firm's License Type

Table 6 shows the data's distribution based on the type of license that the architecture firm does its activities under. The five types of licenses were directly adopted from the Saudi Council of Engineers. The data is relatively equally distributed, with Engineering offices being the most represented type of office license with 31% (n=36). Engineering support services offices are the least represented, being only 7% (n=8) of the replies. The remaining types are sufficiently represented with 5% increments between them.

Firm's Main Areas of Work

The main areas of work of each firm are also shown in table 6, where the percentage of firms that partake in these work activities are presented. It is important to note that more than one activity can be chosen per firm. Design and consultation activities, both architectural and engineering, are the most prominent activities. Each has an approximate inclusion rate of 40%. Project management follows at 33% (n=39) and finally construction is the least represented area of work with only 17% (n=20) of firms undertaking those activities. This shows that there is a preferable sentiment towards managerial and office-based experience-dependent activities in comparison to procurement. These preferred activities rely on the individual's skill set and their ability to outsource these skills to various projects at once rather than focusing all efforts on a limited number of construction activities.

Participant Profession

It can be seen in table 6 that the distribution of data based on the profession of the participants is equally spread, with a small increase in the percentage of architects. Building-related designers are the least percentage of participants, where they only represent 19% (n=22) of the sample. This is because their work heavily intersects with that of an architect, and firms tend to prefer employees that can cover more areas when an expert isn't needed. Nonarchitects makeup 70% of participants, which shows that the Saudi architecture and building production sector is very expansive and diverse regarding architecture. This also shows that a lot of interdisciplinary work is needed and done in the field, which is facilitated by the abundance of various professions that perform supportive activities to architectural design.

Participant Experience in KSA

Table 6 also show the distribution of participants based on experience, where the overwhelming majority (53%, n=61) has less than 5 years of experience in the Saudi architecture and building production field. The percentage of participants descends as the years of experience increases. As the survey didn't focus on collecting participants with a set number of years of experience, this trend is to be expected. This is because professionals with extensive experience in the field aren't readily available, in addition to the fact that only a limited number of them are needed within a single organization.

Participant's Role in Decision-Making

Table 6 shows that the majority of participants (66%, n=76) are decision-makers within their organizations / firms. To further expand this finding, the decision-making capacity's

relationship with the participants' experience was assessed. It can be seen that 78.9% of participants with 21+ years of experience are directly involved in the decision-making process within their organization while 73.7% are partners/owners of the firm itself. This vastly contrasts the 14.4% of participants with less than 21 years of experience that have any form of decision-making capacity. The overall findings can be seen in table 7.

Table 7: Decision-making capacity and experience.

Years of experience	Decision makers (%)	Nondecision makers (%)
Under 5	8.20	91.80
6-10	27.30	72.70
11-20	21.40	78.60
21-30	100	0
Over 30	62.50	37.50

4.2 Data Reliability

As stated in chapter 3.3.5, Cronbach's Alpha and Analysis of Variance (ANOVA) were used to assess the reliability (i.e. internal consistency) of the questionnaire instruments and the data sets collected by it. The study used a significant alpha level of 0.05 when conducting any calculations that require it. Cronbach's Alpha (α) is a statistical test to measure the internal consistency between data sets that use the same measurement instrument. This study used Cronbach's Alpha to measure the internal consistency (i.e. reliability) of the set of questionnaire items. For a reliable measurement instrument, the covariance must be higher in relation to the variance (difference between groups).

Cronbach's Alpha was used as a reliability test to assess the internal consistency within the entire data set. The value was calculated to be $\alpha = 0.854045348893688$. According to Cronbach, values that lie within the 0.8-0.9 show that the data has good internal consistency while anything higher than 0.9 is excellent (Cronbach, 1951). Hence, the data has good internal consistency and is considered valid to deduce findings from.

Single Factor ANOVA was conducted on 47 sets of data, where each set contained either a question directly from the questionnaire or a data set that represents a part of more comprehensive questions in the questionnaire that probe for feedback regarding multiple variables at the same time (for example, rating the level of usage of different digital media technologies). The results of the analysis for the full data set are shown in Table 8.

Table 8: ANOVA for the full data set.

ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	3368440.9	14	73226.976	185.30801	0	1.3682400
Within Groups	2134673.6	540	395.16357	31		61
	16	2	2			
Total	5503114.5	544				
	3	8				

As there are two scales of measurement in the study, the ANOVA test was done two additional times for each group of data sets that share the same measurement scale. These can be seen in tables 9 and 10. Table 9 shows the test results for questions that used the percentage measure scale (out of 100) while table 10 shows the results for questions that use the 7-point Likert-scale.

Table 9: ANOVA for percentage measurement scale questions.

ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	26255.99	19	1381.894	1.581985	0.052141	1.591036
Within Groups	2009094	2300	873.5191			
Total	2035350	2319				

Table 10: ANOVA for 7-point Likert-scale questions.

ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	995.023	25	39.80092	9.034555	7.84E-33	1.509793
Within Groups	13158.96	2987	4.40541			
Total	14153.98	3012				

The results of the ANOVA tests show that questions that use the percentage measurement scale can't reject the null hypotheses. This is because table 9 shows that the F statistic is lower than the F crit, in addition to the P-value being higher than the significance level of 0.05. Regarding questions that use the 7-point Likert-scale as a measurement scale, the null hypothesis can be rejected as the F statistic is much higher than the F crit, in addition to the P-value being extremely close to zero. The findings of table 9 and 10 conclude that questions that use the 7-point Likert-scale can be used to independently measure a variable, while questions that use the percentage measurement scale can't be used independently and must be used in conjunction with other questions to get valid reliable data.

4.3 Digital Media Usage in the Saudi Market

This subsection discusses all findings regarding digital media technologies and their usage in the Saudi architecture and building production sector. The categories of digital media technologies are established based on an extensive literature review as reported in section 3.2.1.

Table 11: Digital Media Familiarity.

Digital Media Technology	Mean	Median	Mode	IQR
Image processing	4.315789	5	6	3
2D + 3D CAD	4.238532	4	7	4
Building information modelling	3.925926	4	3	3
Parametric design tools	3.752381	4	4	3
Big data	3.833333	4	4	2
Machine learning + Artificial intelligence	4.513514	4	4	3
Building-related simulations	4.009434	4	4	2.25

Table 12: Digital Media Familiarity Likert-scale Distribution.

	1	2	3	4	5	6	7
Image processing	12%	11%	13%	12%	15%	18%	18%
2D + 3D CAD	10%	17%	11%	15%	13%	15%	19%
Building information modelling	9%	17%	19%	17%	16%	9%	13%
Parametric design tools	14%	11%	17%	27%	10%	14%	7%
Big data	13%	11%	17%	23%	18%	12%	6%
Machine learning + Artificial intelligence	8%	11%	10%	22%	12%	18%	20%
Building-related simulations	11%	13%	13%	25%	14%	10%	13%

Table 11 presents the familiarity of participants with each digital media technology. The measurement was done on a 7-point Likert-scale where a rating of 7 means that the participants are completely familiar with the digital media technology. Descriptive statistics of the data set are shown. An option of “not applicable” was available to ensure the capture cases where the technology is not relevant to participants or their work. This avoids users skewing results into lower familiarity. Additionally, table 12 shows the percentage ratings of each digital media technology on the Likert-scale.

Generally viewing the data in table 11, all digital media technologies have large interquartile ranges. This means that familiarity between all digital media technologies

varies immensely. Additionally, 4 out of the 7 digital media technologies (parametric design tools, building-related simulations, big data, and machine learning + artificial intelligence) have their peak level of familiarity as 4, which on a 7-point Likert-scale represents a neutral reply. This shows that participants are aware of the advanced capabilities of those digital media technologies but lack the technical skills to utilize them, hence the neutral rating.

Participants' sentiments towards image processing technologies show an interesting pattern, where the mode and median are relatively high with values of 6 and 5 relatively. However, the mean is much lower at 4.31 in addition to having a large IQR of 3. This shows that the technology is relatively well-known, in addition to being used at lower proficiency levels. According to table 11, image processing is the second most known digital media technology.

2D + 3D CAD is the third most familiar digital media technology, which shows an increase in the percentage of familiar participants though higher values of the measurement scale as seen in table 13. Though there is a 17% rise at 2, which is very close to the peak's 19%. This is because 2D + 3D CAD is the most used digital media technology out of all the ones being assessed, in addition to having the second highest extent of usage within the architectural design process. Table 11 shows that although it has a median of 4, which is a neutral point, it has a high mode of 7 at 19% of participants. Additionally, the large IQR of 4 means that the data is horizontally spread, which can be seen from table 12. This broad range of usage combined with the extent means that various positions that require various proficiency and familiarity exist, which can be seen through the seamless steady increase

of the values. The 17% rise means that an abundance of simplistic tasks are available which require basic familiarity.

Tables 11 and 12 show that building information modelling has a peak user familiarity at a mode of 3 with 19%, this means that on average participants don't fully understand the technology and its capabilities. It can be seen from table 12 that though the participants are equally distributed between 2 and 4 at 17%, the percentages drop at higher levels of familiarity. The percentage drops to 9% at 6 and rises again to 13% at 7. The mean is below the neutral point at 3.92, which shows a tendency towards low familiarity. The IQR of 3 shows that there is good dispersion around the mean point.

Table 12 shows that parametric design tools have the highest percentage compared with other technologies at the neutral point and at the least familiarity point with 27% and 14% respectively. The percentage of participants that reported high levels of familiarity drops significantly, going down to 7%. A small 14% hike is seen at 6 but is insignificant as the continuous trend of decreasing remains. Additionally, compared to other technologies, it has the second least percentage of completely familiar users with 7%. This shows that participants are familiar with parametric design tools but only to a basic level of knowledge. Parametric design tools have the lowest mean of all technologies with 3.75, while having neutral dispersing descriptive statistics with a median and mode of 4, and an IQR of 3.

Big data is a technology that is indirectly used in the architectural design process, as it mainly facilitates communications. Due to this nature, table 12 shows that it peaks at the neutral mid-point of the scale while steeply descending in both directions, being steeper

towards higher familiarities. This shows that general knowledge is prevalent, but a minimal percentage of participants (6%) are completely familiar with it. The percentage of participants that have minimal knowledge is 13%, which is double of those that are completely familiar with the technology. This is in line with its values in table 11, where it has the second lowest mean at 3.83. This shows that basic general knowledge is prevalent while proper familiarity is rare, which is why it is the least digital media technology that is fully familiar with participants compared to the others. Additionally, table 11 shows that Big data has the least dispersion, with the lowest IQR of 2.

Machine learning + artificial intelligence digital media technologies exhibit professional-centric behavior in table 12. This is because it has the least percentage of participants at the bottom of the scale while having the highest at its top with 8% and 20% respectively. This is further emphasized by table 11, as the technology has the highest mean at 4.51. These findings show that participants who are familiar with this technology tend to be comprehensively knowledgeable about it when compared to other technologies. This can be related to the extremely technical nature of the technology and its high technological barrier of entry to be able to use the technology. It is also worth noting that a large percentage of users (22%) have medium level knowledge which can be seen in table 11, as the mode is 4. This is because these technologies are currently very hot topics with the rise of language models and image generation. Despite the technical barrier of entry, commercial machine learning and artificial intelligence applications are readily available for anybody to use. This explains why a small percentage of participants (8%) state that they are very unfamiliar with them. The technical barriers are for individuals who want to

write code and use those technologies to do specialized tasks, but these skills aren't needed for ready-built models.

Finally, building-related simulations' data in table 12 shows semi-symmetrical properties. The percentage of participants peaks at the neutral point with 25%, while decreasing while ascending or descending in familiarity. This is also seen in table 11, as the descriptive statistics are all extremely close to the neutral point, while having a low IQR of 2.25. It exhibits the behavior of normal distribution, showing that the technology is commonly known within the Saudi architecture and building production sector.

In continuation, table 13 shows the wide range of digital media applications that are used in the various phases of the architecture and building production design process in the Saudi market.

Table 13: Digital media applications used in each design phase.

Design Phase	Digital Media Applications
Pre-design / analysis	Sketchup, Revit, Photoshop, Grasshopper, Ladybug, Vasari, ArchiCAD, SAP 2000, SPSS, Chat GPT
Conceptual and schematic design	Sketchup, Revit, AutoCAD, rhino, photoshop, twinmotion, Lumion, Rhino, Grasshopper, Teckla Structures, SmartDraw

Design development	AutoCAD, Revit, Rhino, Photoshop, Visual Studio, Sketchup, ArchiCAD, Illustrator
Presentation / documentation	Vray, Sketchup, Lumion, twinmotion, photoshop, InDesign, Revit, Adobe Creative Suite, AutoCAD, Rhino, Bluebeam, Google Sheets, MS Office, Google presentation, 3ds Max, Google Slides
Working / construction drawings	AutoCAD, Revit, CAD, Shinydocs, Bluebeam, Azure, Sketchup, Dreamweaver, ArchiCAD, Excel
As-built documentation	AutoCAD, Revit, Autodesk Recap, CAD, CATIA, Shinydocs, Bluebeam, Word,
Post occupancy evaluation	Autodesk Insight, Photoshop, 3ds Max, Bluebeam, Revit, Entrata, Canva

Table 13 shows findings consistent with those of tables 11 and 11, where digital media technologies are used to various degrees in all design process phases. The variety in digital media technologies used shows that digital media technologies can be adapted to fulfil tasks in any design phase. The extent of the utilization of the technology's capabilities

differs based on the task. Furthermore, 2D + 3D CAD and building information modelling applications are consistently used across all design phases. This shows the versatility and essentiality of those technologies to the Saudi architecture and building production sector.

Finally, figure 3 and 4 shows the survey participants' opinions regarding the different reasons of the utilization and underutilization of digital media technologies in within the architectural design process in the Saudi architecture and building production field.

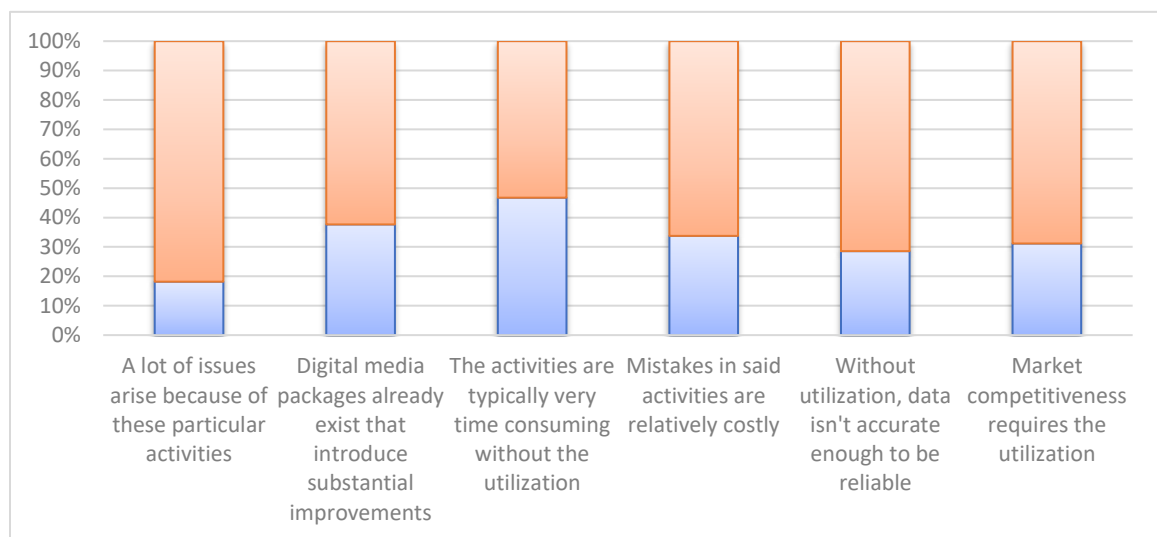


Figure 3: Reasons for utilization of digital media technologies.

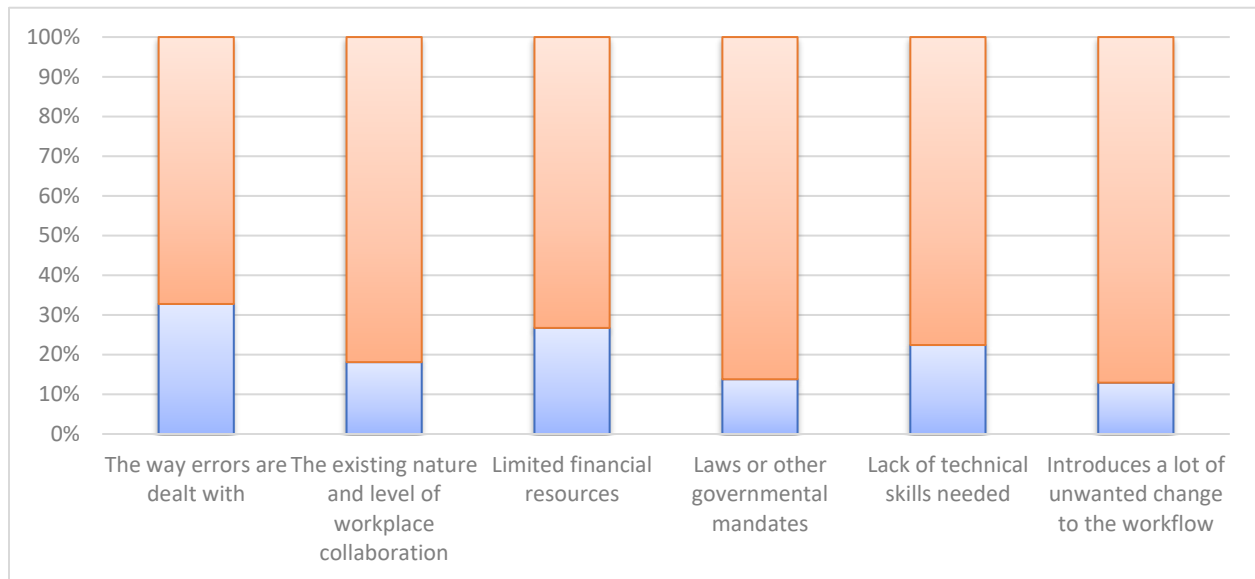


Figure 4: Reasons for underutilization of digital media technologies.

It can be seen in figure 3 that the main reason for adopting digital media technologies is because they save time in time consuming design activities. This is also combined with the fact that digital media applications already exist that satisfy those needs, so the usage and adoption process of those technologies is straightforward. Additionally, utilization is important for the accuracy of the data produced as any mistakes tend to be costly. Finally, market competitiveness demands continuous utilization of digital media technologies.

On the other hand, figure 4 highlights the main reasons that cause the underutilization of digital media technologies. Most importantly, the way errors are dealt with is seen as the biggest obstacle in digital media adoption. This is because errors are identified and treated by human intervention during the design activity itself, which becomes less apparent when done dependently on digital media. Another issue is that the adoption and usage of digital media technologies has inherent costs which deter a lot of interested individuals. Additionally, the technical skills needed for digital media utilization were identified to be

a significant issue. As these skilled individuals either introduce immense increased costs or are not available.

4.4 Usage Patterns of Digital Media Across Different Phases of the Architecture Design and Building Production Processes

This section analyzes the usage patterns of digital media technologies across various phases of the architecture and building production design process. The analysis is done in two steps, where the initial step is assessing the extent of usage of digital media technologies in the complete architectural design process. This is shown in tables 14 and 15 below.

Table 14: Descriptive Statistics of the Extent of Digital Media Usage.

Digital Media Technology	Mean	Median	Mode	IQR
Image processing	4.123894	4	7	4
2D + 3D CAD	4.414414	5	7	3
Building information modelling	4.109091	4	4	3
Parametric design tools	4.04717	4	4	3.25
Big data	4.027778	4	5	3
Machine learning + Artificial intelligence	4.4	4.5	4	3
Building-related simulations	4.165138	4	2	4

Table 15: Extent of Digital Media Usage Likert-Scale Distribution.

	1	2	3	4	5	6	7
Image processing	17%	12%	8%	20%	10%	12%	20%
2D + 3D CAD	9%	14%	9%	18%	16%	14%	20%
Building information modelling	13%	10%	14%	24%	12%	14%	15%
Parametric design tools	10%	14%	14%	23%	12%	13%	13%
Big data	15%	11%	10%	19%	21%	14%	10%
Machine learning + Artificial intelligence	6%	15%	10%	18%	17%	15%	17%
Building-related simulations	10%	18%	11%	16%	12%	17%	17%

Tables 14 and 15 describe the extent of usage of each digital media technology. The measurement was done on a 7-point Likert-scale, where a rating of 7 means that the digital media technology is used intensively in the firm. Table 15 shows the percentage of replies for each rating along the scale in percentages. Additionally, an option of “not applicable” was available to avoid users skewing results into lower values.

Generally assessing table 14, it can be seen that the data is distributed more amongst the higher ratings. Table 15 shows that the peaks have lower percentages, but the values are higher among all the different digital media technologies. Which is seen in the large modes of 7 and 5 in table 14. Image processing, building information modelling, and parametric

design tools peak at the neutral point of the scale, while other technologies peak at different points (and some multiple times) which shows that the extent of usage differs among the digital media technologies.

Table 15 shows that image processing technologies have 3 peaks of very similar heights (17%, 20%, 20%) at both extremes of the scale in addition to the neutral point. This behavior supports the previously established finding from figure 10 that image processing technologies are used extensively at various levels of proficiency. Additionally, they are tied for the most extensively used between all the others (at the 7 point). Consistent dips between those peaks occur, stating that the consensus is split amongst peaks, and intermediate values are ignored. This is highlighted by table 14, where although the mode is 7, the median is at the neutral point and the mean is only 4.12. Additionally, the IQR has a large value of 4 which emphasizes the dispersions of the values between the different peaks at the data.

2D + 3D CAD technologies are extensively used at various levels of complexity throughout the Saudi architecture and building production field. This relationship is seen in table 15 as 68% of participants stated that these technologies are at least used to an appropriate extent (4+ rating), while 50% of participants stated that the technology is extensively used (5+ rating). Additionally, 2D + 3D CAD technologies have the highest peak (20%) at 7 on the measurement scale. These findings deduce that these technologies are thoroughly spread throughout the Saudi architecture and building production sector, while simultaneously being extensively used. The statistics from table 14 describe those findings, where 2D + 3D CAD technologies have the highest mean between all technologies at 4.41.

Additionally, they have a large median and mode at 5 and 7 respectively. This means that the data has leniency towards a higher extent of usage.

Table 15 shows that building information modelling has the highest peak at the neutral point with 24%, while the rest of the sample equally spread around the rest of the scale with minor lenience towards higher extent of usage. This can be seen through table 14, as it has a mean of 4.11 with 4 as both the median and the mode. In correlation with figure 10, these findings can be rationalized due to the reduced average familiarity with the technology. This translates to an average overall extent of usage, in addition to having comparatively unnoteworthy findings at either extremes of the measurement scale.

Table 14 shows that parametric design tools' usage is equally distributed among the different extents of usage except at the neutral (4) point, where the percentage spikes up to 23% as seen in table 15. These results aren't consistent with table 11's findings, where parametric design is seen to have low familiarity (mean = 3.75) with participants. Table 15 shows a mean of 4.04 with a median and mode of 4, stating that the data is limited in usage. This relationship emphasizes that parametric design tools are used to different extents based on the intended usage, and it has nothing to do with the users' familiarity with the technology itself. Additionally, having a mode of 4 in extent of usage and familiarity of the technology shows that the technology is very well known at an elementary level and is being frequently used as such. However, participants report lower average familiarity than usage, which can be interpreted as the technology being used in an isolated nature for specific tasks by people who can sufficiently understand it.

Despite having low familiarity, table 14 shows that big data technologies have higher mode extent of usage of 5 on the measurement scale with 21% as seen in table 15. It has a mean extent of usage of 4.03 and a median of 4, stating that it is generally averagely used. However, the higher mode and the low IQR of 3 means that the data is equally distributed throughout the data set at different extents of usage. This is because these technologies facilitate communications, which are an essential part of any architectural design process. However, it is worth noting that compared to the other digital media technologies, it is the least rated technology at 7 where the extent of usage is the highest.

The aforementioned professional-centric behavior of machine learning + artificial intelligence technologies' is also seen in table 14, where they have the second highest mean of 4.4 in addition to having the second highest median at 4.5. Table 15 highlights that the technologies are comparatively the least used in the least extent of usage (1 on the measurement scale) compared to the other technologies, while having consistent higher values at the other extents (excluding the dip at 3). This means that the technologies are used at similar frequencies in different extents of usage, which translates to the technologies capabilities of being sufficiently useful regardless of the complexity of its area of application. The dips at both 1 and 3 on the scale in table 15 show that machine learning + artificial intelligence technologies are less likely to be used in simpler tasks.

Building-related simulations exhibit unique behavior in tables 14 and 15. Firstly, the technology has the lowest mode between all technologies at 2 with 18% as seen in table 15. These findings are exactly opposite to sentiments regarding its familiarity. In fact, table 15 shows that it comparatively has the lowest percentage (16%) at the neutral point when compared to all the other digital media technologies, while it had the highest in familiarity

at the neutral point as seen in table 12. This unique relationship shows that by just being commonly known in the Saudi market, simulation technologies' potential was fully realized by the field and is being capitalized on. Although having an extremely low mode, building-related simulations have a higher-than-average mean of 4.17 in addition to having a median of 4. However, it has a very large IQR of 4 due to the low mode, which means that the data set is distributed over a large range.

The second step to properly assess the usage patterns of digital media technologies across the different phases of the architecture and building production design phase is to conduct correlational analysis between the extent of usage of digital media technologies and the percentage of work done using those technologies in each architectural design phase. These findings are shown in table 16 and figure 5.

Table 16: Correlational Analysis of Usage Patterns.

	Pre- design / analysis	Conceptual and schematic design	Design development	Presentation / documentation	Working / construction drawings	As-built documentation	Post occupancy evaluation
Image processing	0.200	0.203	0.197	0.262	0.088	0.258	0.164
2D + 3D CAD	0.151	0.276	0.331	0.243	0.295	0.323	0.312
Building information modelling	0.196	0.191	0.228	0.200	0.173	0.250	0.173
Parametric design tools	0.084	0.043	-0.127	0.101	0.075	0.112	0.076
Big data	0.276	0.243	0.081	0.249	-0.016	0.140	0.049
Machine learning + Artificial intelligence	0.320	0.219	0.174	0.241	0.146	0.235	0.073

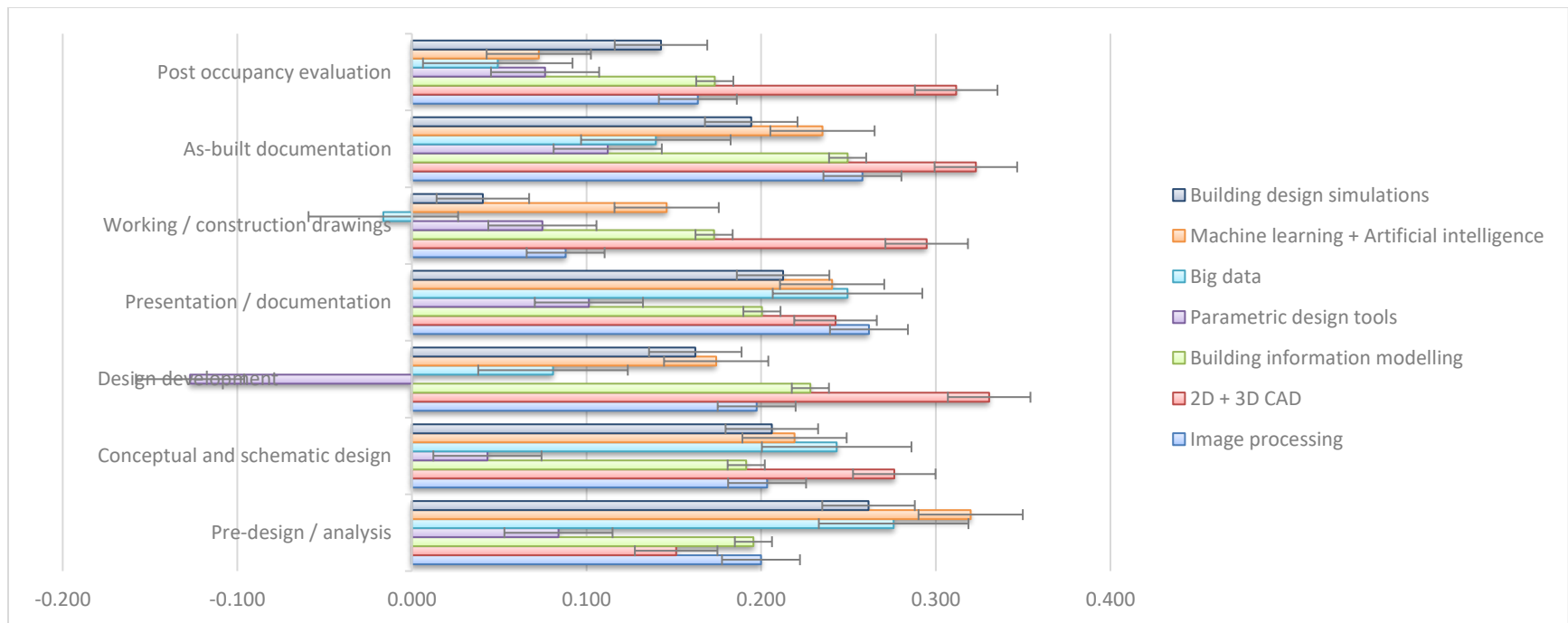


Figure 5: Correlational Analysis of Usage Patterns

Table 16 shows the results of the correlational analysis, where the data represents the correlation coefficient of each design phase with the respective digital media technology. The coefficient can be either negative or positive, where a positive correlation states that as one increases the other does too and vice versa for negative correlations. A color code was added to the table, to graphically highlight the range of values of the correlation coefficient. Figure 5 shows the same data as a bar chart to ease its interpretation. Additionally, error bars were included for a better description of the findings. The values of the correlation coefficients are shown as ratios.

It can be seen from table 16 that different digital media technologies are used to different extents at different architectural design process phases. The predesign phase uses big machine learning + artificial intelligence technologies the most, where they have a high coefficient of 0.32. In addition to using both big data and building design simulation to large extents at coefficients of 0.276 and 0.261 respectively. Parametric design tools are noted to be the least used digital media technology as they have a low coefficient of 0.084.

Table 16 shows that the conceptual and schematic design phase uses digital media technologies in a relatively balanced distribution. This is except for parametric design tools as they tend to have a low coefficient of 0.043. The most used technology is 2D + 3D CAD with a coefficient of 0.276, followed by big data at 0.243. The rest are evenly used at approximate coefficients of 0.2.

Design development has a unique characteristic shown in table 16, where they have a negative correlation with parametric design tools. This means that the greater the extent of digital media usage during this phase, the less likely it is to utilize parametric design tools.

Its highest correlation is with 2D + 3D CAD at 0.331, followed by building information modelling and image processing with coefficients of 0.228 and 0.197 respectively. The other digital media technologies have much less utilization.

Table 16 highlights that the presentation / documentation phase exhibits similar behavior to the conceptual and schematic design phase. This is where all the digital media technologies have high correlations except for parametric design tools which have a low correlation coefficient of 0.101. On the other hand, all the other digital media technologies have correlation coefficients of 0.2 or higher, where image processing technologies have the largest coefficient at 0.262.

According to the data in table 16, the working / construction drawings design phase exhibits a negative tendency towards all digital media technologies other than 2D + 3D CAD, which has a correlation coefficient of 0.295. This is only followed by building information modelling and machine learning + artificial intelligence technologies at relatively significant coefficients of 0.173 and 0.146 respectively. All the other digital media technologies have negligible correlation coefficients, in addition to big data having an insignificant negative coefficient of -0.016.

Table 16 showcases that the as-built documentation phase follows a similar pattern that is exhibited in the presentation / documentation phase and the conceptual and schematic design phase. This pattern shows high levels of digital media usage with high correlation coefficients across most digital media technologies. The highest coefficient is with 2D + 3D CAD at 0.323, while the lowest coefficients belong to big data and parametric design tools with 0.14 and 0.112 respectively.

Finally, post occupancy evaluation exhibits similar behavior to that of the working / construction drawings phase. This is because table 16 shows that most of the digital media technologies have low correlation coefficients except for 2D + 3D CAD which had a high correlation of 0.312. The other technologies that have significant correlations have coefficients that are half of that of 2D + 3D CAD, while the remaining technologies have negligible correlations.

By assessing the full data set through table 16 and figure 5, several trends can be deduced regarding digital media technologies and architectural design phases. Firstly, conceptual and schematic design, presentation / documentation, and as-built documentation phases all show a pattern of high and wide digital media extent of usage, where multiple technologies are likely to be used extensively. Inversely, working / construction drawings and post-occupancy evaluation phases exhibit the opposite behavior. They have lower than average extent of digital media usage for most of the technologies except for 2D + 3D CAD. In fact, table shows 16 that 2D + 3D CAD technologies are extensively used throughout most design phases except for the predesign / analysis phase. On the other hand, parametric design tools expressed consistent low correlation coefficients with all the architectural design phases, making it the least used technology.

4.5 Level of Digital Media Diffusion

This chapter builds on the findings when assessing the usage patterns and aims to discover the level of digital media diffusion in the Saudi architecture and building production sector. Tables 14 and 15 focused on the extent of digital media usage, which need further data relative to the context of adoption to fully describe the Saudi market. Hence, tables 17 and

18 were developed to comparatively assess the usage of digital media technologies between themselves.

Table 17: Usage of Digital Media Technologies Ranked.

Digital Media Technology	Mean	Median	Mode	IQR
Image processing	2.896552	2	1	3
2D + 3D CAD	2.978022	2	2	3
Building information modelling	3.373626	3	3	2
Parametric design tools	4.285714	4	4	2
Big data	4.05618	4	4	2.5
Machine learning + Artificial intelligence	4.369565	5	6	3.75
Building-related simulations	4.544444	5	7	3.25

Table 18: Digital Media Usage Ranking Likert-Scale Distribution.

	1	2	3	4	5	6	7
Image processing	31%	21%	16%	9%	11%	6%	6%
2D + 3D CAD	25%	27%	15%	11%	5%	8%	8%
Building information modelling	16%	16%	30%	13%	7%	10%	8%
Parametric design tools	8%	5%	13%	30%	21%	14%	9%

Big data	7%	18%	12%	20%	20%	13%	9%
Machine learning + Artificial intelligence	15%	10%	11%	10%	14%	22%	18%
Building-related simulations	10%	12%	11%	12%	13%	17%	24%

Tables 17 and 18 show digital media technologies ranked based on their usage within the participants' contexts. The 7 digital media technologies were ranked against each other from 1 to 7, where 1 means the most used while 7 means the least. No two technologies can have the same rank from the same participant. Additionally, as with previous data sets, a "not applicable" option was available to prevent uninformed input that skews the data set. When "not applicable" is chosen, the ranking is done for the remaining technologies up to their count.

Table 17 shows that image processing is comparatively ranked as the most used digital media technology within firms in the Saudi architecture and building production field. This was seen through its mode of 1, in addition to having a median of 2. It also has the lowest mean value of 2.9, which ranks it as the most used digital media technology. The second most used technology is 2D + 3D CAD, which had the highest rating at number 2 as seen in table 18, in addition to being the second most rated at number 1. This shows that these two technologies are the most prominent in Saudi architecture and building production sector while having very close means.

Building information modelling technologies were ranked third on the usage rating scale, which is consistent with its average extent of usage that has slight lenience towards extensive usage. Table 17 shows that it has both a median and a mode of 3, in addition to a mean of 3.73. With a low IQR of 2, it can be seen from table 18 that the data is converging around 3 with a large percentage of 30% while remaining tightly clumped.

Table 17 shows that the fourth and fifth ranked digital media technologies are ambiguous. This is because parametric design tools are ranked as the median digital media technology, where their usage is just average with a median and mode of 4. However, big data also has a median and mode of 4. Although Parametric design tools have a higher mean of 4.2 they have a less diverging data set with an IQR of 2.5. On the other hand, big data has the better ranking of 4.06 but they a slightly higher diverging data set with an IQR of 2.5. In conclusion, based on the means, big data is the fourth rated digital media while parametric design tools are the fifth. This deduction is further supported by table 18, where big data's larger dispersion of data also benefited its higher-ranking rates. It is worth noting that parametric design is rated higher at lower ranks than at higher ranks, meaning that usage is abundant at a basic level and rarely is it extensively used as the forefront technology is projects. In fact, it is more likely to have a minor role than a major one in an architectural and building production design process. It is worth noting that big data technologies have the second highest number of "not applicable" replies. This is consistent with the study's previous findings, having low familiarity with high extent of usage. The data trends suggest that it isn't particularly used by the firm itself as a tool within the architectural and building production design process, but it is extensively used to facilitate communications.

Machine learning + artificial intelligence technologies' usage ranking in tables 17 and 18 show patterns that conform with the professional-centric behaviors that were established earlier. Since these digital media technologies require intensive technical knowledge to be used, they are consequently less used than other technologies on average. This is reflected in table 18 as they are the most chosen as the 6th rank and are second highest at the 7th rank. They have a high median and mode of 5 and 6 respectively, in addition to the largest IQR of the set at 3.75. This large dispersion explains why its mean is only 4.37 when it is expected to be much higher.

Finally, table 17 shows that building-related simulations are ranked last in terms of usage when compared to the other digital media technologies. Table 18 shows that the technology consistently had the least percentage of votes at higher ranks while gaining more as the rankings descend. It has the highest mean at 4.54, in addition to the highest mode of 7. Although its median value is 5, its low IQR of 3.25 in combination with having 7 as a mode resulted in it being ranked as the least used digital media technology. This shows that they are used much less than other technologies and are seen as supportive technologies that undertake tasks that exclusively fulfill specific requirements.

Table 19: Percentage of Work Using Digital Media.

Architectural Design Phase	Mean	Median	Mode	IQR
Pre-design / analysis	53.44828	60%	70%	50
Conceptual and schematic design	57.32759	60%	60%	40
Design development	53.62069	50%	40%	50

Presentation / documentation	57.58621	65%	90%	60
Working / construction drawings	58.36207	60%	100%	47.5
As-built documentation	56.03448	60%	40%	40
Post occupancy evaluation	56.37931	60%	100%	50

The percentage of work done using digital media technologies in different phases of the architecture and building production design process is seen in tables 19 and 20. The descriptive statistics shown in table 19 are for the ranking participants gave each architectural design process phase, while the distribution of said ranking are shown in table 20. Ratings were done on a percentage scale, with the option of “not applicable” being available. A general view of table 20 shows that trends can be identified within the data. Firstly, 10% digital media usage has the least percentage of participants throughout all the design phases. Furthermore, values below 40% digital media usage have low numbers of represented participants’ sentiments. This means that most of the work within the architecture and building production design process is done using various digital media technologies.

Table 20: Percentage of Work Using Digital Media Percentage Distribution.

	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Pre-design / analysis	9%	8%	7%	8%	10%	9%	11%	13%	10%	11%	10%
Conceptual and schematic design	5%	5%	8%	6%	15%	7%	17%	9%	9%	10%	14%
Design development	5%	6%	12%	9%	17%	4%	12%	7%	9%	10%	14%
Presentation / documentation	5%	6%	12%	6%	13%	4%	6%	12%	12%	17%	12%
Working / construction drawings	5%	4%	6%	11%	15%	9%	10%	6%	13%	11%	15%
As-built documentation	6%	8%	5%	6%	17%	9%	12%	8%	13%	6%	17%
Post occupancy evaluation	6%	7%	7%	6%	13%	9%	8%	14%	12%	9%	14%

Tables 19 and 20 show that the predesign / analysis phase has lenience towards being dependent on digital media usage. This can be seen from its mode of 70% of work using digital media, in addition to having 55% of participants stating that the percentage of work doing using digital media is 60% and more. A similar trend is seen in the conceptual and schematic design phase, where it peaks much higher where 17% of participants stated that 60% of work is done using digital media. This 60% is also both the mode and median of the data set as stated in table 19. Additionally, table 20 highlights that 59% of participants stated that 60% or more of work is done using digital media.

Table 20 shows that the design development phase is equally distributed above and below the 50% mark. Table 19 shows that the median is 50%, with a lower mode at 40%. 49% of participants stated that 50% or less of the work is done using digital media while 51% stated the opposite. This shows that opinions vary regarding the best ways to undertake the phase, where both analogue and digital approaches are equally used in the Saudi architecture and building production field. Table 19 shows that the presentation phase is heavily more lenient towards having a higher percentage of work being done using digital media. This is supported by its mode at 90% of work done, in addition to its high median of 65%. Furthermore, table 20 highlights that 59% of participants state that 59% or more of work is done using digital media. Additionally, the mean of all participants opinions is 57.59% which heavily leans into the phase being dominantly done using digital media technologies.

Table 19 shows that the working / construction drawings phase has the highest average percentage of work done using digital media at its mean of 58.36%. Referencing the data from table 20, the data set has two peaks of 15% at 40% and 100% of work being done

using digital media. The rest of the data is equally distributed between those two peaks (except for two dips at 50% and 70%), while only 26% of participants state that 30% or less of the work is done using digital media. This is supported by an IQR of 47.5, which is similar to the range between the two mentioned peaks. A similar relationship is seen with the as-built documentation phase, where table 20 shows two peaks (17%) at 40% and 100% of work being done digitally. The key difference here is that the values oscillate between the two peaks, in addition to being equally distributed. These result in a high median of 60% paired with a relatively low mode of 40%. Finally, the post occupancy evaluation phase exhibits a similar trend. The two peaks that can be seen are at 70%, and 100% of work being done digitally. These results in table 19 present a median of 60% in addition to a shared mode of 100% and 70%. As stated in the literature review, these three phases (in addition to presentation / documentation) are concerned with documentation activities at various points of the architectural design process. Therefore, users are likely to exhibit similar sentiments towards the three phases. These shared sentiments in turn were translated into similar characteristics within their data sets in table 20.

4.6 Readiness of the Saudi Architecture and Building Production

Industry

To establish an assessment for the readiness of the Saudi industry for digital media adoption, the study relies on previously established definition of automation. Automation was established in this study as complete independence from human intervention and total reliance on digital media technologies. This section discusses the participants' sentiments towards automation both from their expectant perspective and the actual automation within the field. By depending on those two variables, assessment of the current situation in the

Saudi market can be done, in addition to any perceived potential which in turn represents the readiness of the sector. Hence, the expectant automation is analyzed first. This can be seen in tables 21 and 22.

Table 21: Expectant Automation.

Digital Media Technology	Mean	Median	Mode	IQR
Pre-design / analysis	54.22414	55%	80%	50
Conceptual and schematic design	49.13793	50%	50%	50
Design development	52.06897	50%	50%	50
Presentation / documentation	52.24138	50%	30%	40
Working / construction drawings	54.91379	50%	80%	40
As-built documentation	54.05172	50%	50%	50
Post occupancy evaluation	59.48276	60%	50%	50

Table 21 shows the descriptive statistics of the participants' expectant level of automation of each design phase. The data is presented on a percentage measurement scale. An option of "not applicable" was available to avoid participants randomly guessing values they aren't sure of. The full data set's distribution is seen in table 22 below

Table 22: Expectant Automation Percentage Distribution.

	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Pre-design / analysis	9%	7%	8%	6%	9%	16%	8%	12%	16%	8%	10%
Conceptual and schematic design	4%	11%	13%	8%	12%	14%	7%	11%	9%	10%	5%
Design development	5%	10%	10%	7%	9%	14%	10%	11%	13%	9%	7%
Presentation / documentation	4%	10%	4%	16%	8%	14%	10%	14%	7%	7%	10%
Working / construction drawings	4%	6%	6%	8%	14%	15%	11%	7%	15%	9%	8%
As-built documentation	7%	7%	6%	9%	12%	13%	10%	11%	10%	12%	9%
Post occupancy evaluation	4%	5%	6%	9%	5%	17%	10%	8%	10%	14%	14%

By examining tables 21 and 22 together as a whole, it can be seen that each design phase exhibits unique behavior. This shows that each design phase has unique characteristics that interact differently with expectant automation. Additionally, the mode percentage of user' ratings can be seen in most design phases at 50% expectant automation. Such behavior shows that there are uncertain speculations towards automation in the Saudi architecture and building production field that are accompanied with acceptance. This means that the sentiment towards automation is volatile and can be influenced by external factors either positively or negatively.

Investigating each design phase individually, it can be seen from table 22 that the pre-design / analysis phase is comparatively perceived to have a higher percentage of automation as it has the third highest mean at 54.22. This can be seen in relation to table 23 through the two peaks at 50% and 80% automation, in addition to the fact that only 39% of participants think that 40% or less of it should be automated. This is consistent with the findings from chapter 4.3, emphasizing its reliance on digital media rather than human intervention.

The conceptual and schematic design phase shows a balanced distribution of participants' sentiments in table 22, where 48% of participants believe that less than 50% of the design phase should be automated while 52% believe the opposite. As the mode is at 50% automation with 14% of participants, this follows the general trend of the data where neutral sentiments prevail. Table 21 shows that the phase is slightly skewed towards lower percentage of automation with a mean value of 49.14%, and a median and mode of 50%. This develops the findings from chapter 4.3, identifying that the phase is equally dependent on digital media and human intervention.

Although table 22 shows the data set peaking at 50% perceived automation, the design development phase is slightly leaning towards a higher percentage of perceived automation. This is because only 41% of participants think that less than 50% of the phase should be automated, in addition to the mean of 52.07% that is seen in table 21. This is consistent with the phase's nature, whereas based on findings from chapter 4.4 the design development phase covers a wide range of digital media technologies usage and to varying extents.

The presentation / documentation phase is shown in table 22 to be perceived as being more capable of being automated. As only 42% of participants think that less than 50% of the phase should be automated. Additionally, it has minor peaks at both 50% and 70% automation, although the actual mode according to table 21 is at 30%, showing lenience towards higher percentage of automation. Compared to findings in chapter 4.4, the results are consistent with the phase's heavy reliance on digital media. This shows that human intervention isn't necessary for the phase's efficiency, and it can be phased out with the adoption of appropriate digital media technologies.

Table 22 shows the working and construction phase having two modes of 15% at 50% and 80% automation. Only 38% percent of participants believe that less than 50% of the design phase needs to be automated, in addition to having a mean expectant automation rating of 54.91% according to table 21. It is the second highest mean expectant automation rating from the entire data set. These findings are consistent with those established in chapter 4.5, stating that working / construction drawings is a heavily digitalized architectural design phase that relies more on digital media technologies rather than human intervention. Although the digital media technologies efficiently adopted are limited, as seen in 4.4. As-

built documentation phase exhibits very similar behaviors, where according to table 22 only 41% of participants stated that the phase needs less than 50% automation. Additionally, data is equally distributed between 40% to 100% automation. This shows that the data is skewed towards higher levels of automation which is seen by its mean of 54.05% in table 21. Finally, post-occupancy occupancy evaluation exhibits the same trends but with a much higher lenience towards higher percentages of expectant automation. It has the highest mean between all phases at 59.48% as seen in table 21, with table 22 showing that only 29% of participants stating that less than 50% of the design process needs to be automated. Working / construction drawings, as-built documentation and post-occupancy evaluation phases follow the same trend as the presentation / documentation phase. This relationship was also seen in the findings of chapter 4.5. Hence, these findings and sentiments highlight the fact that documentation activities in the Saudi architecture and building production field are extremely reliant on digital media while having the highest capability amongst all other architectural design phases of majorly abandoning human intervention.

The participants' perception of expectant automation potential is dependent on various external and contextual factors, in addition to personal views. Figure 6 shows the reasoning behind the aforementioned sentiments.

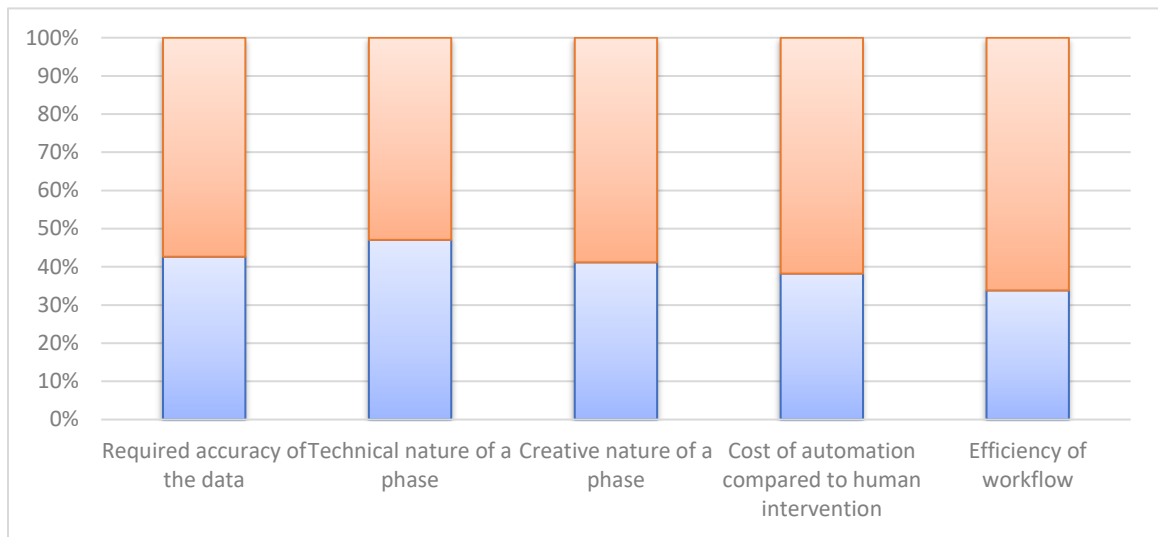


Figure 6: Reasons for Expectant Automation.

It can be seen in figure 6 that the technical nature of the architectural design phase is the main factor that affects its perceived automation. This directly connects to the required level of human intervention according to the participants. The required accuracy of data also continues this notion, where technical design activities are preferred to be done automatically due to digital media's consistent accuracy. The creative nature of the phase is consistent with previous findings, where digital media and analogue methods are equally utilized. Based on the data, initial creative activities can be heavily automated while advanced ones require human intervention. The cost accompanying automation is stated to be a significant factor, yet less significant than the ones mentioned earlier. This shows that although cost is an existing barrier, it can be justified if the more prominent barriers are overcome. Finally, the least significant barrier is the workflow efficiency, where automation will theoretically affect it positively, but the initial disruptions introduced, and the unknown duration of those disruptions act as a barrier.

As the participants' perceived automation was already assessed, further assessment of the actual levels of automation in the Saudi architecture and building production field allows for the exploration of potential automation opportunities. Table 23 shows the actual automation in participants' firms/organizations.

Table 23: Actual Automation.

Digital Media Technology	Mean	Median	Mode	IQR
Pre-design / analysis	48.10345	50	50	47.5
Conceptual and schematic design	48.62069	50	50	47.5
Design development	51.2069	50	30	50
Presentation / documentation	47.75862	40	40	40
Working / construction drawings	53.18966	50	40	47.5
As-built documentation	54.05172	50	70	50
Post occupancy evaluation	51.55172	50	40	50

The data in table 23 shows similar tendencies and trends as that in table 21. However, differences appear at different intervals of the graph for different design phases. Those differences represent areas of readiness for automation or areas of overinvestment in digital media technologies. These can be seen in Table 24 and figure 7.

Table 24: Readiness for Automation.

Design Phase	Expectant	Actual	Readiness (E/A)
Pre-design / analysis	54.22414	48.10345	12.72%
Conceptual and schematic design	49.13793	48.62069	1.06%
Design development	52.06897	51.2069	1.68%
Presentation / documentation	52.24138	47.75862	9.39%
Working / construction drawings	54.91379	53.18966	3.24%
As-built documentation	54.05172	54.05172	0.00%
Post occupancy evaluation	59.48276	51.55172	15.38%

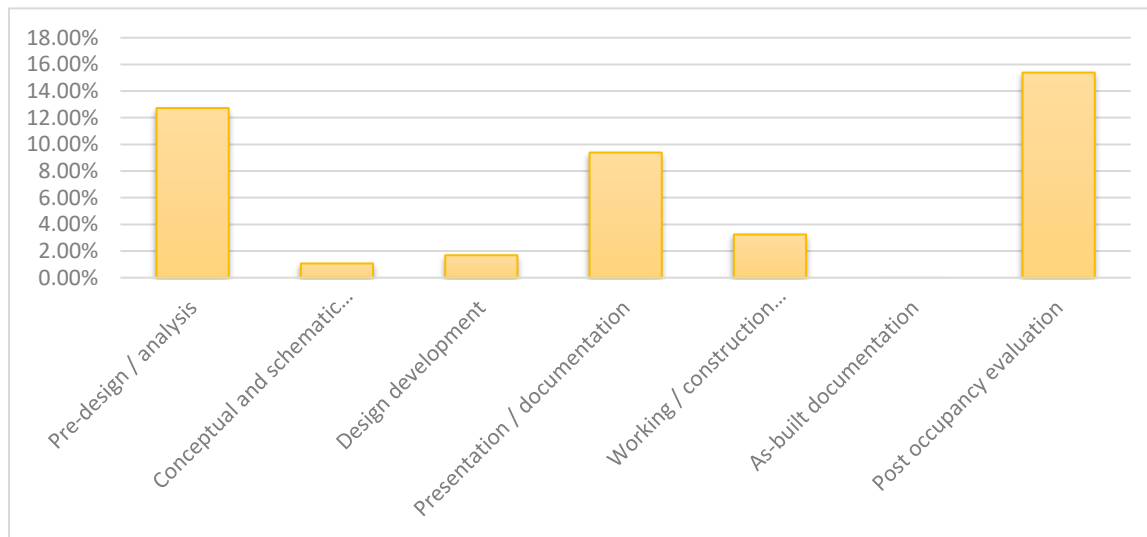


Figure 7: Average readiness for automation of design phases.

Table 24 and figure 7 show the relationship between the expectant level of automation for each design phase (table 21) and the actual existing level of automation within the Saudi architecture and building production sector (figure 23). By using the mean values for expectant and actual automation for each architectural design phase, areas of readiness for automation were identified. Readiness was presented in percentages by dividing the average expectant automation by the average actual automation. This readiness represents the potential of the Saudi architecture and building production sector for the adoption of digital media technologies. Based on this approach, the percentage increase in expectant automation is calculated by using actual automation as the reference point. Additionally, it is worth noting that all average expectant automation values are higher than the actual automation.

By analyzing table 24 and figure 7, it can be seen that the post-occupancy evaluation phase has the highest readiness for automation at 15.38%. This is consistent with previous findings, as the phase is extremely reliant on digital media rather than human intervention.

As-built documentation and working / construction drawings phases show a much lower potential for automation, although they share all characteristics with post-occupancy evaluation. This finding shows that although they are heavily reliant on digital media, they still require adequate human intervention. The presentation / documentation shows high readiness of 9.39%, which is consistent with its previously established dependency on digital media technologies. It is worth noting that this design phase also shared its characteristics with working / construction drawings, as-built documentation, and post occupancy evaluation. However, our findings from table 24 and figure 7 show that on a deeper level, the group of four design processes that are concerned with documentation (to a certain extent) separates into sets of two. One that has higher readiness for automation, and the other which still needs human intervention.

The predesign / analysis design phase shows the second highest readiness for automation at 12.72%. This is a much higher percentage when compared to the conceptual and schematic design phase, which is another early erratic design phase. This staggering difference can be associated to the difference in the nature of the design activities happening within each phase. The pre-design has a lot of preparatory work that involves data collection and analysis, which are all technical tasks that are done through digital media applications with minimal human intervention. Users only need to accurately input data and the rest is done automatically. On the other hand, conceptual and schematic design phases are creative processes that rely on design decisions to be made by users, which explains why they have minimal potential for automation. This is also seen in the design development phase, since a lot of decisions are primarily made by the designers.

Conclusively, the level of satisfaction with automation was measured from both the employees' and the clients' perspectives. The findings are seen in figure 8.

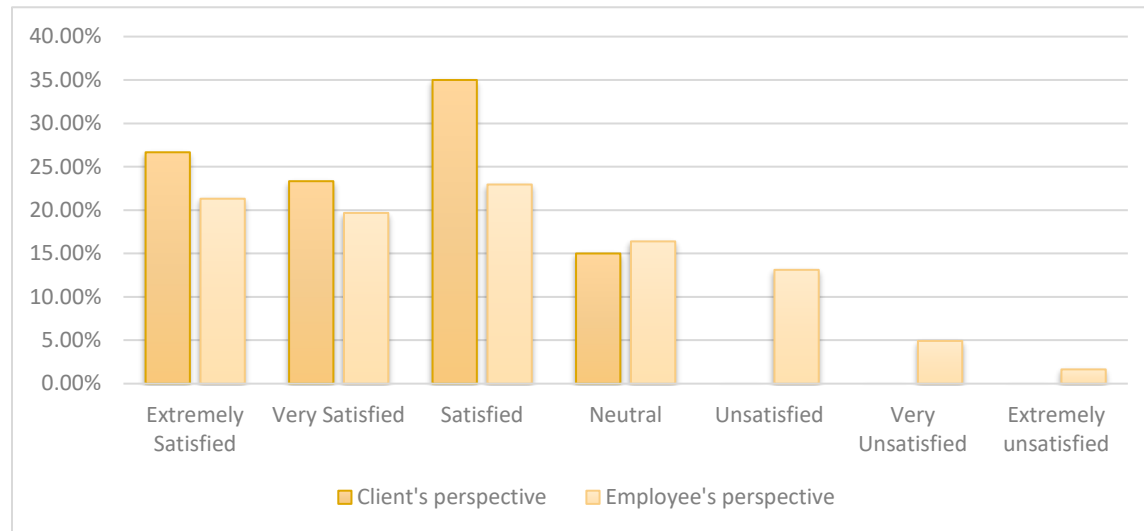


Figure 8: Satisfaction with automation.

As seen in figure 8, clients and employees have slightly different sentiments towards automation. It is worth noting that this question was optional to avoid participants guessing random answers. Clients expressed varying levels of satisfaction while none expressed any dissatisfaction with the technology. This also explains the difference in the percentages between clients and employees at the positive rating scale, since no clients exist at the negative scale. Most clients (35%) are satisfied with the current level of automation of the Saudi architecture and building production field, 26.67% percentage stated they are extremely satisfied while 23.33% were very satisfied. Only 15% experienced neutrality towards automation. On the other hand, employees shared the data's trend with clients at the positive ratings of the measurement scale, where most were satisfied then extremely satisfied and finally very satisfied. However, the percentages are much lower at 29.95%, 21.31%, and 19.67% respectively. However, a larger percentage (16.39%) expressed neutrality than clients. Assessing negative sentiments, a total of 19.67% of participants

expressed dissatisfaction with automation, which is descending in percentage as the unsatisfaction increases. The data set for employees shows that although the general sentiment is similar to that of clients, the responses are more varied. Additionally, clients only express neutral or positive outlooks because they are receiving the results of automation without facing any of the difficulties introduced by it. Finally, it is worth noting that reporting was done based on the participants' opinion regarding the clients. This means that the data set is opinionated and can be misleading, as clients can simply not express honest sentiments to the employees for various reasons.

4.7 Qualitative Analysis

This section covers various topics that fall under the previously established reasoning questions. These are concerned with interpersonal sentiments towards technologies and the context. The findings are presented in figures 9-16.

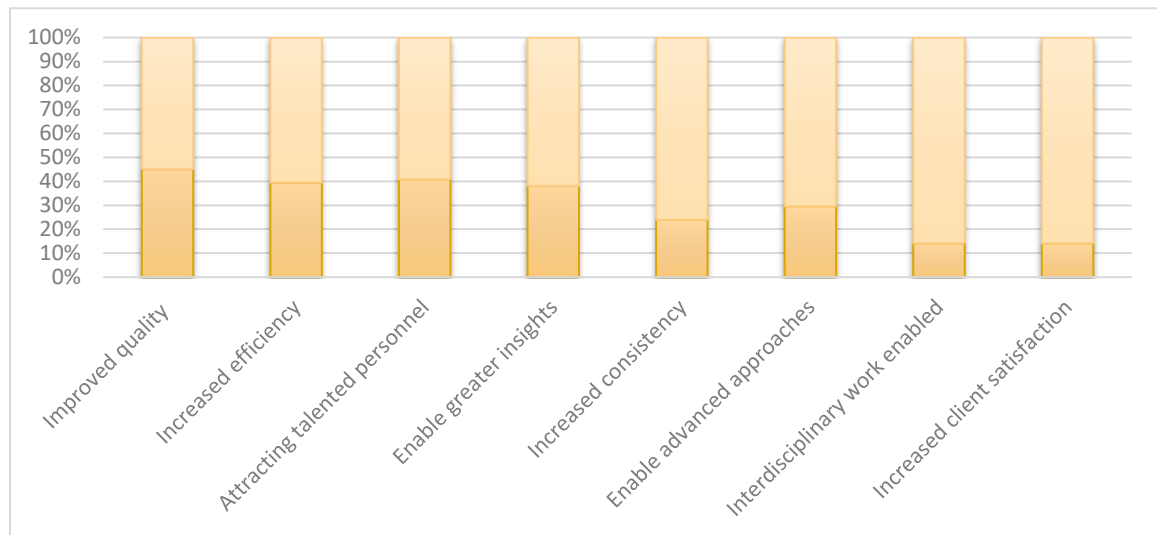


Figure 9: Aspects that drive digital media adoption.

Figure 9 shows aspects that positively drive the adoption of digital media technologies into the Saudi architecture and building production sector. Firstly, the attraction of talented personnel who are eager to learn and develop their technical skills within contexts that are

continuously evolving by introducing new digital media technologies is the highest rated aspect that is concerned with the users and their psychological sentiments towards the adoption. A recurring theme for aspects that motivate adoption is their advancement of the architectural design process. This can be seen in figure 9, as the highest ranked aspects are all directly beneficial to the design process. The adoption process heightens quality, efficiency, enables deeper insights into projects, and enables the usage of advanced approaches. It is worth noting that improving interdisciplinary approaches during the architectural design process is comparatively not highly regarded, which shows that the Saudi architecture and building production field doesn't acknowledge the importance integrated design processes. Additionally, client satisfaction is given minimal importance too, as they don't typically have deep insights into the intricacies of the architectural design process.

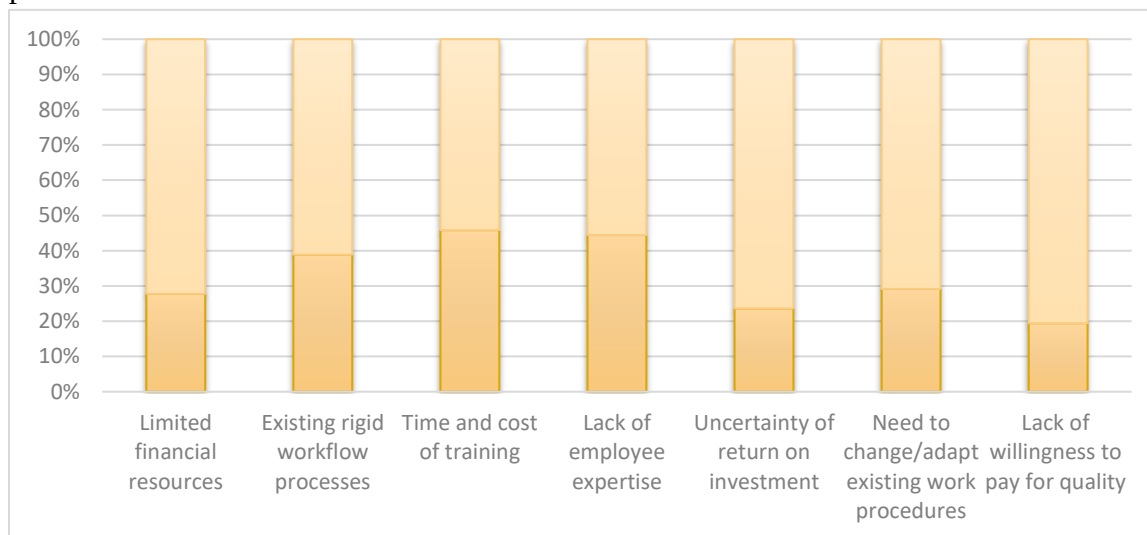


Figure 10: Aspects that limit digital media adoption.

Aspects that hinder the adoption of digital media are seen in figure 10. The most prominent category of limiting aspects is cost related, where the time and financial costs needed to properly adopt digital media technologies is the most prominent one. This is consequently followed by the fact that financial resources are limited and need convincing justification

for investment in digital media technology. Investment in digital media is even more difficult as the return on investment isn't easily obtainable and is often achieved as systematic improvements within the firm / organization rather than financial gains. Finally, clients aren't willing to pay for advancements introduced by digital media adoption, forcing firm owners to fully handle the costs. From figure 10 it can be seen that all financial limiting aspects are interconnected, where the more intricate the aspects get, the less they are noticed by the participants. The remaining limiting aspects are categorized as organizational, focusing on workflow and managerial issues. The most prominent one is the lack available expertise readily available, which in turn results in increased costs for training or recruitment. Additionally, having an existing rigid workflow process discourages the introduction of any disruptions even if they are beneficial when the disruption ends. Finally, rethinking the existing workflow procedures to implement newly adopted digital media technologies is considered a jarring task that introduces unwanted disruptions, going back to the previously mentioned aspect.

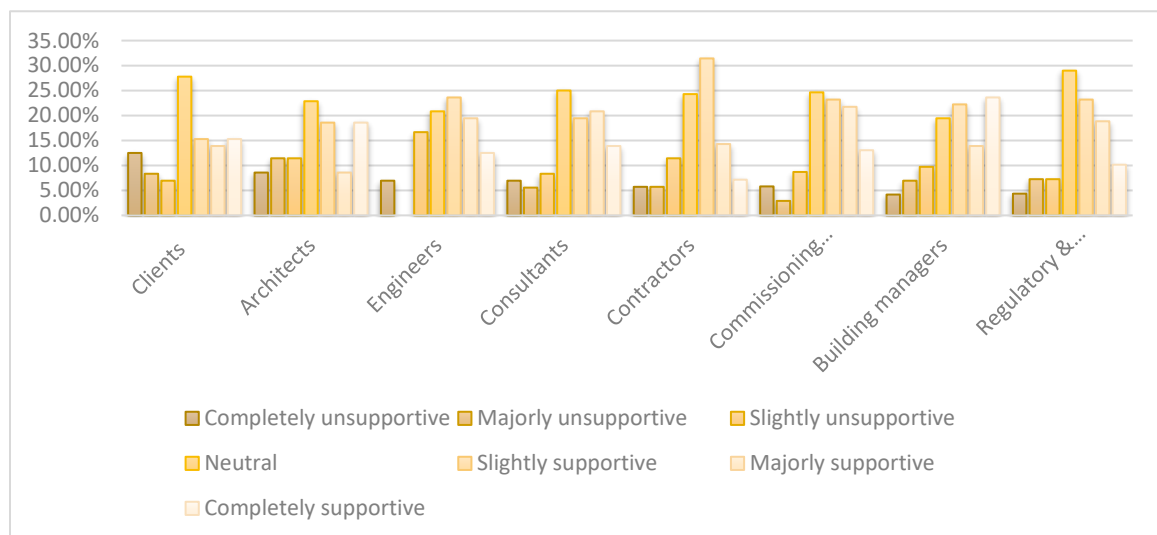


Figure 11: Stakeholder's support of digital media adoption.

Stakeholders are key individuals who have significant direct effect on the architectural design process, which subsequently makes them very influential in digital media adoption processes. Figure 11 shows different stakeholders' sentiments towards the adoption of digital media technologies. Values are obtained from participants based on their observations. Most stakeholders are neutral from the peaks of the data sets; However, their general stances differ based on the distribution of the respondents' replies among the other levels of supportiveness. Clients for example have their peak of 27.78% at neutral level of support but only 27.77% of participants were unsupportive of adoption. Their data leans towards being supportive but they are the least supportive stakeholders comparatively. Architects share similar sentiments as clients, but they have a lower peak of 22.86% while having their data set more spread out through the different levels of support. They have the second lowest average supportiveness. Although contractors have the highest peak in all the data sets across all the different supportiveness levels at 31.43% in slight supportiveness, they only rank 3rd to last in average supportiveness as 47.14% of responses are distributed at the lower levels of supportiveness while only 21.43% are higher than the peak.

Regulatory bodies are noticeably supportive as seen in figure 11, due to the peak (28.99%) at neutral support and its subsequent comparatively large percentages at slight (23.19%) and major (18.84%) supportiveness. They have an average supportiveness of 4.57%. Engineers and consultants both have the same average supportiveness of 4.625% but differ in the distribution of their data sets. Engineers have a peak of 23.61% at slight supportiveness and the data is normally distributed around that peak, while consultants have a 25% peak at neutral supportiveness but have 54.16% of respondents as supportive

to varying degrees while only 20.83% are unsupportive. Commissioning agents have a peak at neutral supportiveness of 24.64% while 57.97% of respondents being supportive. Only 17.4% of respondents were unsupportive, resulting in the second highest average supportiveness level. Finally, building managers are the most supportive stakeholders, with a peak of 23.61% at complete supportiveness. It can be seen from figure 11 that most of the data skews towards supportiveness which can be seen by comparing supportive respondents' percentage (59.72%) to the unsupportive ones (20.73%). By assessing figure 11, it can be seen that stakeholders that are directly involved in the architectural design process vary in their responses whereas others tend to be overly supportive of digital media adoption. These findings conclude that digital media adoption is encouraged by managerial and regulatory bodies in the Saudi architecture and building production field but are less accepted by individuals who are responsible for the implementation and running of the digital media technologies.

Further assessment of the reasoning behind the lesser support of digital media technologies by architects and engineers was done by probing for more personal sentiments towards digital media adoption. Participants were asked about encouragement of innovation, efficient resource (time, financial, and personnel) allocation, morale, recognition, and appreciation of internally developed innovations, and finally the availability of proper training. Figures 12-16 show the results of those findings, all using 7-point Likert-scale as a measurement tool.

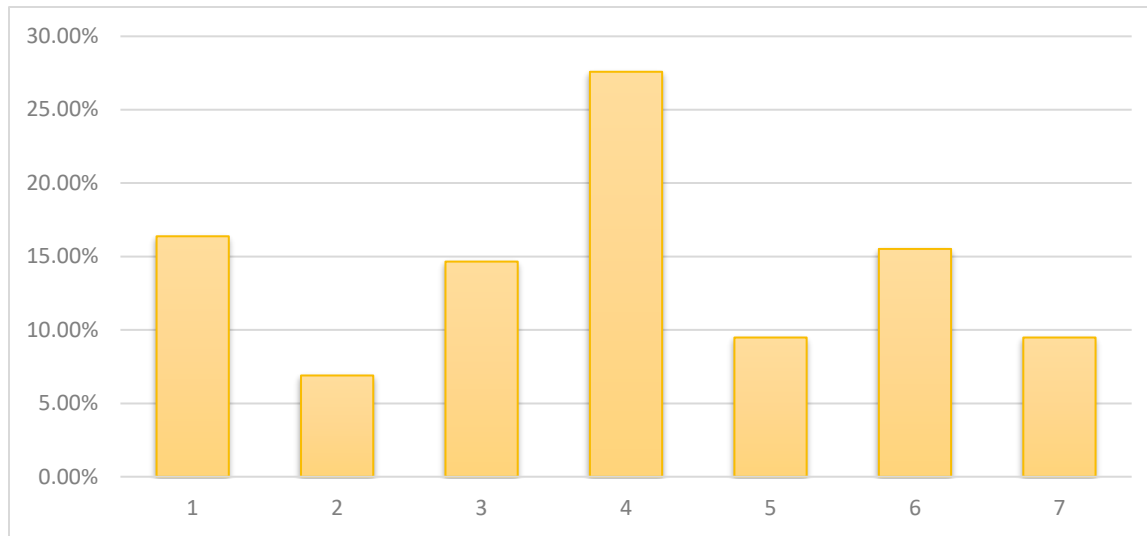


Figure 12: Encouragement of innovation and development.

Participants were asked if they were encouraged to be innovative and seek out better ways of operating in their work. Figure 12 shows that the majority (27.59%) has a neutral stance, while the data slightly skews towards negative sentiments with a mean of 3.91 on the Likert-scale. The difference is minor, as 34.48% of participants have positive opinions while 37.94% expressed negative ones. The lenience towards negativity can be explained by the peak at 1, showing that 16.38% of participants believe that they are extremely discouraged to be innovative. These findings show that the Saudi architecture and building production field doesn't encourage digital media innovations, hence individuals are less likely to innovate.

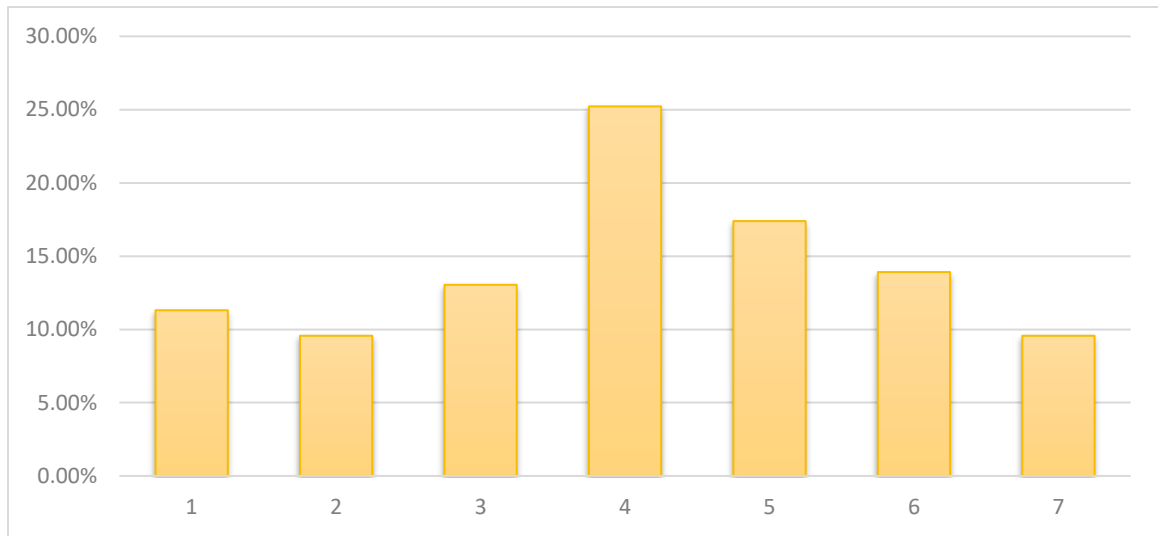


Figure 13: Availability of resources to support innovation adoption.

Figure 13 shows the participants' sentiments towards the availability and efficient usage of resources for the adoption and development of digital media innovations. Resources refer to time, funding, and personnel needed. The general sentiment is neutral, where the average rating is 4.07, in addition to having a peak of 25.22% at 4. Except for the minor increase at 1, the data follows a normal distribution, meaning that the participants don't exhibit strong opinions regarding the phenomenon being assessed.

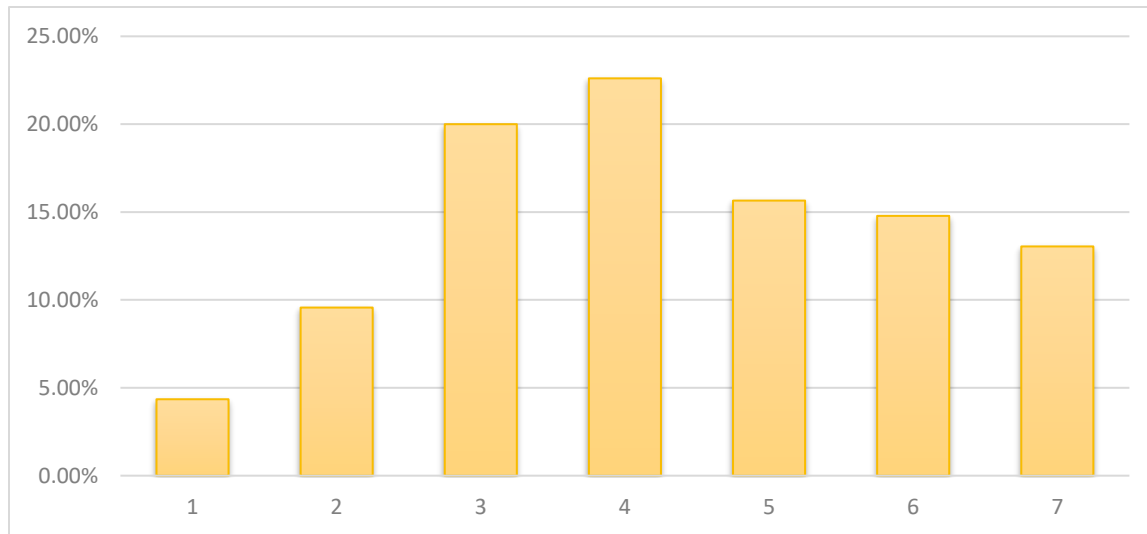


Figure 14: Effect of innovation adoption on morale.

The findings showcased in figure 14 evaluate the effects of digital media innovation adoption on the morale of participants. The data shows a normal distribution trend, with a peak at 4 with 22.61%. Although normally distributed, the data set isn't symmetrical. 33.92% of participants expressed that digital media innovations negatively affect their morale while 43.47% were positively impacted. This can be seen graphically in figure 26, as the graph is skewed towards positive impacts. Additionally, most of the negative sentiment is slight, where 20% are at the 3 ranking while only a total of 13.92% is represented in the bottom two options combined. The data has an average ranking of 4.32 at the Likert-Scale, which is in line with the assessment of the study.

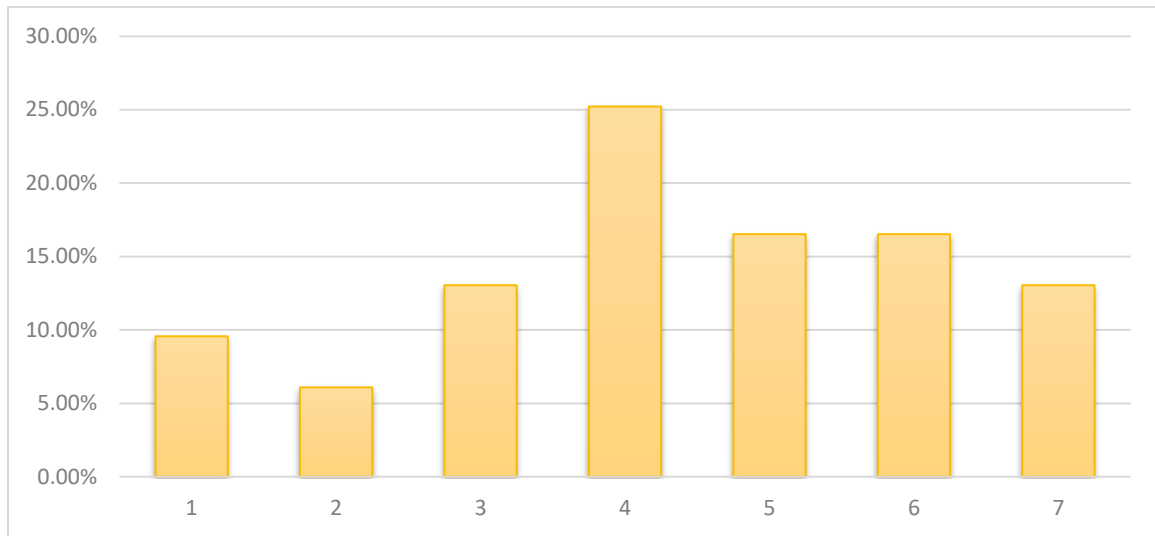


Figure 15: Recognition and reward for innovation.

Figure 15 shows the extent that respondents feel that their personal innovations are recognized and rewarded. The highest percentage of respondents (25.22%) voted neutrally. However, the data shows leniency towards a positive sentiment, as 46.08% of responses were distributed at the positive range of the scale while only 28.7% were at the negative side. Additionally, the average ranking on the Likert-scale is 4.35, which supports the data's slight leniency towards a positive outlook. These findings show that digital media innovations within the Saudi architecture and building production field are recognized but not to a degree that is too high. These findings are consistent with figure 26, where the effect on morale shows a similar trend. It is deduced that morale is directly correlational to recognition and reward.

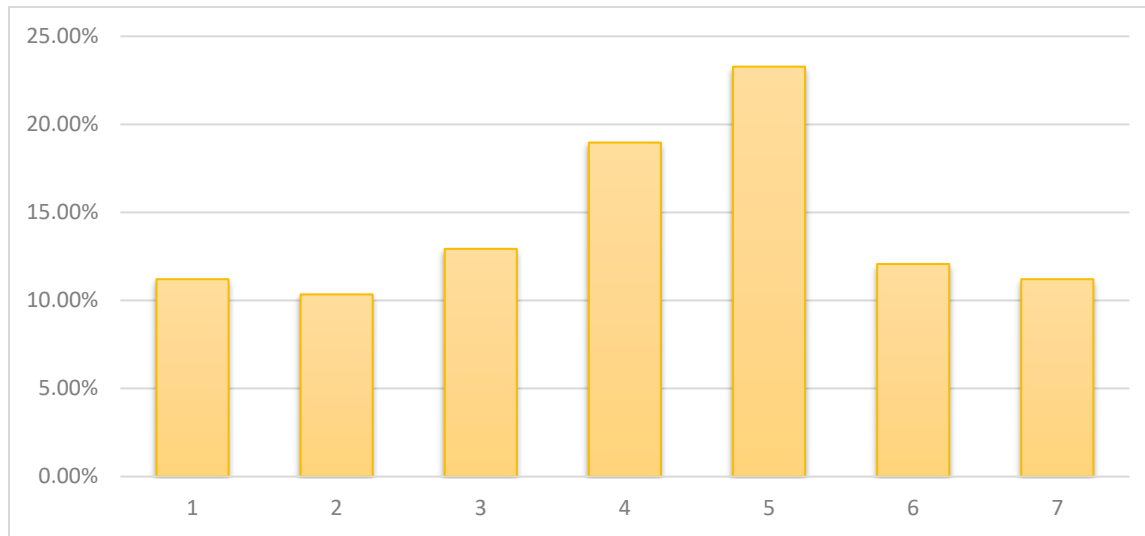


Figure 16: Availability of adequate training.

The data of figure 16 that measures the availability of adequate training exhibits unique behavior. It peaks at 5 with 23.28% unlike all the previous data sets. However, the average rating is only 4.14, which is significantly lower than where it peaks. This is because although the peak is positive, the higher positive ranks don't follow suit and have low percentages of 12.07% and 11.21%. These numbers are within range of the values at lower percentages, which is why the average rating reflects those findings. Conclusively, the data has normal behavior at rankings under 5 (with a slight increase at 1) but they have a sharp drop at more positive ratings. Projecting those findings on the Saudi architecture and building production sector, it can be deduced that training is available but not up to a professional completely comprehensive level.

4.8 Satisfaction with Digital Media

This section analyzes the satisfaction with digital media usage in the Saudi architecture and building production sector. The analysis focuses on the relationship between different demographic groups and their sentiments regarding digital media usage within their contexts. To initiate the analysis, it must be first ensured that a tangible relationship exists

within the data set. Table 25 shows that chi-squared test was used to ensure that the data exhibits unique behavior.

Table 25: Chi-Squared test for satisfaction with digital media.

<i>Actual</i>								
	Extremely Satisfied	Very Satisfied	Satisfied	Neutral	Unsatisfied	Very Unsatisfied	Extremely unsatisfied	Sum
Clients	16	14	21	9	0	0	0	60
Employees	13	12	14	10	8	3	1	61
Total	29	26	35	19	8	3	1	121
<i>Expected</i>								
	Extremely Satisfied	Very Satisfied	Satisfied	Neutral	Unsatisfied	Very Unsatisfied	Extremely unsatisfied	Sum
Clients	14.38	12.89	17.36	9.42	3.97	1.49	0.50	60
Employees	14.62	13.11	17.64	9.58	4.03	1.51	0.50	61
Total	29	26	35	19	8	3	1	121
Alpha					0.05	Chi²	0.0306	

Table 25 shows the distribution of the replies on a 7-point Likert-scale. Data represents stakeholder's satisfaction with automation, which according to the study's established definition represents their satisfaction with the current level of digital media adoption and diffusion. The expected data is a statistically produced data set that equally distributes the sample across the findings, while ensuring that it exhibits the same statistical behavior. By using the actual and expected data sets, the resultant value for chi-squared analysis was

0.0306, which is well below the established alpha of 0.05. This means that the data set has unique behaviors that result in tangible relationships being deduced.

The expectant level of adoption and its accompanying potential are used to assess satisfaction with digital media based on different demographic categorizations. These variables were chosen as they represent satisfaction in relation to architectural design process phases, where satisfaction is represented in wanting more digital media adoption and diffusion in comparison to what is currently available. There are three trends that the data can exhibit, it can have high positive potential which shows high levels of satisfaction with digital media usage and the want for more adoption and diffusion. Low potential means that the current level of digital media usage is satisfactory with no need for expansion in usage. Lastly, negative potential means dissatisfaction with a sentiment of reduction in the usage of digital media in the design phase. Table 26 shows the first set of variables, where firm size is assessed against satisfaction with digital media adoption and diffusion across the design phases.

Table 26: Firm Size and Satisfaction.

	Pre-design / analysis	Conceptual and schematic design	Design development	Presentation / documentation	Working / construction drawings	As-built documentation	Post occupancy evaluation
Under 10	16.00%	2.52%	3.49%	13.08%	7.97%	-0.87%	18.01%
11-50	13.18%	1.25%	1.35%	9.24%	3.25%	0.00%	15.63%
51-100	13.53%	3.38%	4.23%	11.72%	7.07%	0.50%	16.84%
101-200	13.24%	2.48%	3.45%	10.05%	5.77%	-0.62%	17.53%
201-500	15.03%	3.17%	2.11%	7.63%	7.51%	-0.92%	18.14%
501-1000	19.22%	1.05%	6.19%	8.33%	1.95%	-6.67%	18.92%
Over 1000	10.10%	3.09%	0.19%	6.56%	1.31%	-1.49%	14.34%

A general look at the data from table 26 shows that the pre-design and the post-occupancy evaluation phases have the highest satisfaction across all demographics, while as-built documentation is the only design phase with negative satisfaction. The different demographics show similar trends with minor differences. Firms with less than 10 employees have high satisfaction with intentions of expanding digital media usage in most design process phases. They also have the highest satisfaction at 7.97% in the working / construction drawing phase, which is a phase that has high variety between the data sets. Firms with 51-100 employees exhibit identical trends to firms with less than 10 employees, with the only difference being that they are satisfied with digital media usage in the as-built documentation phase. Additionally, all their satisfaction values are slightly lower than firms with under 10 employees. Finally, firms with 101-500 employees (includes two data sets) exhibit similar behaviors. The range has unsatisfactory digital media usage in the as-build documentation phase, in addition to showing high positive satisfaction at the post occupancy evaluation design phase.

Firms with 11-50 employees follow the typical data distribution of the set except for the as-built documentation phase, where its value of 0% satisfaction shows satisfaction without any sentiments towards extra usage. On the other hand, firms with 501-1000 employees show an odd high percentage of satisfaction in the design development phase while expressing the most negative sentiment through the entire data set at the as-build documentation phase with -6.67% satisfaction. Finally, firms with over 1000 employees exhibit lower satisfaction compared to other firm sizes across all design phases except for the conceptual phase, where they have a satisfaction rating of 3.09% which is in line with the satisfaction throughout that phase.

Table 27: Firm type and Satisfaction.

	Pre-design analysis	Conceptual / and schematic design	Design development	Presentation / documentation	Working / construction drawings	As-built documentation	Post occupancy evaluation
Consultant Engineer Office	14.88%	1.92%	5.39%	12.30%	9.87%	-0.35%	18.08%
Engineering Consultations Office	14.55%	1.21%	5.08%	9.81%	6.90%	-0.18%	20.91%
Engineering support service offices	16.98%	5.57%	2.70%	15.08%	11.39%	-0.39%	15.77%
Professional engineering companies	10.85%	0.91%	2.92%	9.31%	5.02%	-0.97%	14.09%

Engineer Office	11.93%	2.09%	2.31%	6.00%	3.64%	-1.35%	15.58%
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Table 27 shows the level of satisfaction in relation to the type of firm. A general view of the data shows that the post occupancy evaluation phase has the most satisfaction of all the other phases. This is followed by the predesign / analysis phase, then the working / construction drawings phase, and finally the presentation / documentation phase. As-built documentation shows dissatisfaction with negative potential throughout. All the types of offices share the same general sentiments, while exhibiting some outlier behaviors. Consultant engineering offices show a high level of satisfaction with digital media usage in the design development phase with a 5.39% potential rate. This sentiment is also shared with engineering consultation offices, where they have a 5.08% potential rate at the design development phase. These two office types are the only ones with significant satisfaction at the design development phase. Additionally, engineering consultation offices have the highest satisfaction in all the data set with 20.91% at the post occupancy evaluation phase. Engineering support services offices exhibited significantly high levels of satisfaction with digital media usage throughout the data set, excluding design development and as-built documentation. They have the highest satisfaction at the predesign phase with 16.98%, the conceptual design phase with 5.57%, the presentation / documentation phase with 15.08%, and the working / construction drawing phase with 11.39%. Professional engineering companies consistently had the lowest satisfaction throughout the different design phases in comparison to the other types of offices. Finally, engineering offices have typical satisfaction across the architectural design phases. However, they exhibit steep drops in satisfaction in the presentation phase and the as-built documentation phase with 6% and -1.35% respectively. These are both the lowest satisfaction values in their design phases.

Table 28: Profession and Satisfaction.

	Conceptual and Working / Post						
	Pre-design analysis	/ schematic design	Design development	Presentation / documentation	construction drawings	As-built documentation	occupancy evaluation
Engineer	10.63%	1.13%	2.29%	7.12%	3.25%	-0.84%	16.11%
Architect	12.72%	1.06%	1.68%	9.39%	3.24%	0.00%	15.38%
Building-related designer	12.83%	2.78%	3.87%	11.89%	7.20%	0.17%	16.78%
Technical assistant	13.08%	6.00%	1.60%	9.17%	3.47%	0.19%	17.50%

Table 28 shows satisfaction with digital media usage in relation to the profession of the participants. The data follows a similar trend seen in tables 26 and 27, where the predesign and post occupancy evaluation phases have the highest satisfaction followed by the presentation phase at a relatively lower level. Post occupancy evaluation is the phase with the highest percentage of satisfaction with digital media usage while as-built documentation is the lowest. However, unlike tables 26 and 27, the as build documentation phase shows average satisfaction instead of dissatisfaction. Only engineers are dissatisfied with a rating of -0.84%. Other than that, the values are low but positive. Meaning that that no need for scaling down of digital media usage is expressed by the participants. The data set in table 28 shows that no profession is comprehensively more satisfied than the others, as each has different sentiments towards different phases.

It can be seen from table 28 that engineers and architects share similar trends, where architects consistently expressed satisfaction more than engineers. Additionally, engineers always had higher satisfaction than architects in phases where both expressed low percentages of satisfaction. This is also seen in the as-build documentation phase, as engineers are the only profession that expressed dissatisfaction throughout the entire set with a value of -0.84%. Building-related designers expressed similar sentiments, but they had more satisfaction than architects and engineers in all phases. Additionally, they had an exceptionally high satisfaction at the working / construction phase at 7.20%, almost double of all the other professions. They also had the highest satisfaction within the presentation phase with 11.89%.

Finally, technical assistants had the highest satisfaction at the predesign and post occupancy evaluation phases with 13.08% and 17.5% respectively. It is worth noting that two design phases have the highest satisfaction rating throughout this data set and all the other data sets analyzed. Table 28 also shows that technical assistants are the only professionals that have a significant percentage of satisfaction at the conceptual design phase with 6%. Although not a significant finding, it is worth noting that technical assistants have the lowest satisfaction rating in design development with 1.6%, which is an already lowly rated design phase through all data sets.

Finally, the last variable for assessing satisfaction with digital media usage is the number of years of experience. Those findings can be seen in table 29. By generally assessing the table, the data set follows a similar pattern to the one seen in tables 26-28. There are high levels of satisfaction in the predesign and the post occupancy evaluation design phases, with lower but still relatively high levels of satisfaction at the presentation / documentation phase.

By assessing each design phase individually, it can be seen from table 29 that conceptual and schematic design phase exhibits low, but positive satisfaction percentages. The design development phase shares a similar pattern but has a peak of 5.52% satisfaction within the data. The working / construction drawings phase has varied finding, but all are within the positive satisfaction range. Finally, the as-built documentation phase contains the lowest satisfaction percentages out of all the data set. Though most are slight and insignificant, the data is either at values around 0% satisfaction, which translates to sufficiency with the current digital media usage, and negative values that represent dissatisfaction combined with the sentiment of reducing digital media usage within the architectural design phase.

Table 29: Years of Experience and Satisfaction.

	Conceptual and Working / Post						
	Pre-design /	schematic	Design	Presentation /	construction	As-built	occupancy
	analysis	design	development	documentation	drawings	documentation	evaluation
Under 5	13.18%	1.25%	1.35%	9.24%	3.25%	0.00%	15.63%
6-10	12.78%	3.15%	4.04%	12.45%	7.20%	0.17%	16.58%
11-20	14.12%	1.92%	5.52%	13.02%	9.76%	-0.69%	17.88%
21-30	10.98%	0.94%	0.56%	10.45%	17.34%	-2.05%	10.70%
Over 30	11.47%	1.89%	2.66%	6.17%	3.63%	-1.35%	15.32%

Analyzing the data of table 29 based on the number of years of experience, it can be seen how satisfaction with digital media changes as the years of experience increases. This is especially visible in the presentation / documentation phase, as the satisfaction percentage steadily increases to a peak of 13.02% at 11-20 years of experience, then steadily falls back down. The same behavior is seen in the working / construction drawings phase, where the percentage of satisfaction steadily increases until it peaks at 21-30 years of experience with the highest satisfaction percentage of the entire set at 17.34%, then drops sharply to 3.63% satisfaction. This value after the drop is similar to the initial value at the under 5 years of experience.

Table 29 shows that participants with less than 5 years of experience exhibit the general data trends explained earlier regarding their satisfaction with digital media across the design process phases. The same can be said about participants with 6-10 years of experience, as no outliers exist in their data. The only notable thing is that they expressed the highest satisfaction with as-built documentation at 0.17%. Individuals with 11-20 years of experience exhibit abnormal levels of high satisfaction across various design phases. They have the highest satisfaction at the predesign phase with 14.12%, the highest at the design development phase with 5.52%, the most at the presentation phase with 13.02%, and finally the greatest at post occupancy evaluation with 17.88%. It can be deduced from table 26 that individuals with 11-20 years of experience are the most satisfied with digital media and are most likely to want more adoption and diffusion.

Table 29 showcases two unique findings regarding the satisfaction of people with 21-30 years of experience. Although they follow the general trend of the data set, it can be seen that they have the highest percentage of satisfaction at the working / construction drawings

phase with 17.34%, in addition to having the lowest most negative percentage of satisfaction at the as-built documentation phase with -2.05%. Furthermore, their satisfaction with digital media usage in the post occupancy evaluation phase is comparatively low at 10.7%. They even have the lowest satisfaction percentages at the conceptual and schematic design phase and the design development phase with 0.94\$ and 0.56% satisfaction respectively. These findings show that although the data follows the general trend of the complete data set, individuals with 21-30 years of experience are the least satisfied with digital media technologies through the design process phases, except for the working / construction drawings phase. Finally, individuals with over 30 years of experience are seen to follow the general data trend without any unique characteristics.

CHAPTER 5

Discussion and Conclusion

This chapter provides an overview of the study, stating the interpretations of the study's findings within the Saudi architecture and building production sector. Additionally, those findings are compared with other studies in different contexts to comparatively analyze the levels of digital media diffusion. Additionally, recommendations are proposed for the Saudi architecture and building production field. The limitations of the study are highlighted at the beginning of this chapter, as they affect the interpretations of the findings. Finally, research prospects that further expand the scope of the findings are proposed.

5.1 Discussion

This section compares the study's findings and their interpretations to the findings of different studies that covered similar topics in different countries. This comparison the establishment of Saudi Arabia's level of digital media diffusion in relation to various contexts, in addition to highlighting key differences between contexts. Additionally, those comparisons' results provide new perspectives for opportunities that are not utilized by the Saudi architecture and building production sector. Finally, they serve as a benchmarking process that helps in establishing recommendations for the Saudi architecture and building production field.

As the study adopted an expansive comprehensive approach, no identical study with the same scope was found. Instead, studies that tackle individual areas similar to parts of the research being conducted were adopted for the discussion. Studies in literature focus on either a singular digital media technology or on one variable that affects the general adoption and diffusion of digital media.

For instance, a study was conducted in China to assess the adoption of building information modelling technology in the architecture and building construction sector (Chen et al., 2019). The research took a managerial centric approach for the study instead of a technical one. By assessing the factors that affect the adoption and diffusion process, the study found that the general added benefits of building information modelling were the major driving factors while its complexity was the main deterrent. These are consistent with findings from figure 9 in section 4.7, as the added benefits introduced by digital media are the greatest drivers for digital media adoption. Additionally, figure 10 shows that the sentiments towards barriers of adoption are similar, as the technical difficulties introduced by the adoption remain a big issue for both studies.

Chen also stated that managerial support is crucial for the adoption and diffusion process, as it can either hinder or promote successful adoption and diffusion processes. This coincides with findings from chapter 4.7, as participants regularly stated that support within their context was an important driving factor. Another interesting managerial finding by Chen was that engineering firms found that organizational readiness was crucial for the diffusion of building information modelling while construction firms didn't. This is in line with observations from figure 11 in chapter 4.7, where it was deduced that stakeholders that are directly interacting with digital media technologies are more reluctant in the

adoption process when compared to others. Finally, Chen found younger Chinese firms to be more accepting of adopting new digital media technologies. According to table 23 and 26 from chapter 4.8, Chen's statement has some merit in the Saudi architecture and building production field. This is because it was observed that firms with lower number of employees have higher percentage of satisfaction with digital media technologies, and they exhibit tendencies of wanting more adoption and diffusion within their firms. Referencing table 23, the smallest size firms have the highest percentages of satisfaction and in turn adoption of digital media technologies. Table 26 reiterates those findings but from an individual perspective, where it was found that years of experience are negatively correlated to the satisfaction and willingness to indulge in adoption or innovation activities.

Mollaoglu conducted a comparative study between three countries assessing the diffusion of digital media innovations in relation to the stakeholders' support (Mollaoglu et al., 2016). The countries in the study are India, Turkey and Indonesia. It was found that the characteristics of the adoption process varies based on the stakeholders than initiate the adoption process in addition to the nature of the innovation itself. India was stated to have the highest rate of adoption, but they had extremely low initial innovation level. This means that they strongly adopt new digital media technologies, but they don't develop them themselves. Turkey and Indonesia on the other hand have high rates of innovation but they differ in their behavior after the development of the innovation. Turkey tends to have much lower diffusion after the initial introduction of the innovation, while Indonesia has consistent adoption and diffusion throughout. According to findings in chapter 4.7's figure 12, it can be seen that the encouragement of innovation is relatively low in the Saudi architecture and building production market. Though the study's findings show that

sufficient support for innovation is available, the innovation and development process itself isn't encouraged. This shows that Saudi Arabia is more in line with India's approach, where adoption and diffusion are immense, but the development of those digital media innovations is limited.

A unique situation can be seen when comparing Saudi Arabia's approach to Malaysia's, which is completely centered around innovating rather than adopting digital media technologies as stated by Lai (Lai et al., 2016). According to Lai, Malaysia's approach directly intersects with the adoption of digital media innovations which in turn emphasizes the importance of adoption and diffusion of digital media technologies. Saudi Arabia's architecture and building production sector is reminiscent of Malaysia's in essence, where the contextual elements are present except for the motivation or encouragement. Lai highlighted that there are two ways for the diffusion of digital media technologies into the architecture and building production sector, namely digital media innovation creation and digital media adoption. The Saudi context is familiar with the adoption of digital media but is limited in terms of innovation creation. The study's findings show that the potential is present for innovation creation but is unrealized. However, it is worth noting that for the adoption such an approach in the Saudi context a lot more freedom and individuality in work needs to be introduced, which introduces difficulties. This is seen in the example of Indonesia, as the domination of team-oriented work directly hinders the individuality that is needed for innovation creation (Lai et al., 2016).

As a continuation to the discussion, Panuwatwanich assessed the importance of the readiness of the Australian architecture and building production sector for digital media innovations (Panuwatwanich et al., 2012). Their findings state that the readiness for digital

media adoption is mainly affected by contextual and managerial factors rather than technical ones, namely leadership, team climate and organizational culture as independent variables. This is stark contrast to the study's findings about the Saudi architecture and building production field, where the aspects are all technical. These findings are explained by Panuwatwanich's study though, as the usage of advanced digital media technologies is considered an existing basic characteristic of the architectural sector. This difference is because the Australian architecture and building production sector is much more developed than the Saudi one, which results in their assessments being completely different. This can be seen as the benefits and barriers to adoption established through the study aren't even considered as such in Panuwatwanich's study, highlighting the fact that those characteristics of digital media technologies are considered an intrinsic part of the field. Panuwatwanich's study has innovative design solutions, innovative design activities, and advanced digital media technologies' utilization as independent variables, further highlighting the fact that the two countries are operating under marginally different contexts.

To compare the study's findings to a similar context, an analysis of the study that Almontaser conducted was done, where they assessed the adoption and implementation of building information modelling technologies into the Saudi architecture and building production field. The main barriers identified were the lack of interest from customers and key industry stakeholders, technically inexperienced individuals working using building information modelling, and limited mentorship from experienced users in leadership roles. The study's data agrees with parts of the findings and contrasts with others. For instance, data shows that clients and most key stakeholders are actually highly supportive of digital

media adoption. Only architects and engineers exhibit lower levels of support which was deduced to be because they need to deal with the issues that are introduced with adoption of digital media technologies. Regarding the limited technical expertise, data also expressed the severity of this barrier. This can be seen through figure 10 in chapter 4.7 where the top two aspects that limit digital media adoption are the time and cost of training and the lack of employee expertise. These two are the barriers established by Almontaser, though this research didn't assess the influence of digital media champions (i.e. experienced users that help in the adoption) so no comments can be done on that.

5.2 Conclusions

This section provides a summary of the major conclusions of the study. The conclusions are mapped to the study objectives. Additionally, this summary sufficiently satisfies the previously established research objectives.

Digital Media Technologies in Use in the Saudi Market

The main used digital media categories are image 2D + 3D CAD (mean = 4.414) and building-related simulations (mean = 4.165), where the most used software packages are AutoCAD, ArchiCAD, and Revit. Parametric design (mean = 4.027) and big data (mean = 4.02), technologies were used the least. It was inferred that parametric design tools have a low extent of usage due to their highly technical nature, while big data technologies' low extent of usage has been linked to its usage in communication software where users don't knowingly interact with the technology itself.

Users have neutral familiarity with digital media technologies, which is clearly shown in sections 4.3 and 4.4 This highlights the fact that awareness of digital media technologies

and their capabilities is present, but users aren't technically familiar enough to capitalize on them as highlighted in sections 4.5 and 4.7. The following are additional prominent findings of the study:

1. CAD technologies (for 2D and 3D) have a broad range and extent of usage. This means that digital media technology is used to varying levels of proficiency throughout the architectural design process. Additionally, an abundance of simplistic tasks are done using 2D + 3D CAD which require minimal familiarity with the technology.
2. Big data technologies are mostly known on a basic level, while advanced comprehensive familiarity is very uncommon. They ranked the least familiar digital media technology compared to the others.
3. Machine learning and artificial intelligence have an extremely high technical barrier of entry if they are to be used to their full potential. Additionally, they are currently extremely hot topics with the rise of predictive language models and image generation. This results in a substantial number of individuals that have very limited knowledge about the technology but regularly use it.
4. Building-related simulations are commonly known and used in the Saudi architecture and building production field.
5. 2D + 3D CAD and building information modelling technologies are the most used digital media technologies in the different phases of the architectural design process.

6. The most common reason for the utilization of digital media technologies is because they save a lot of time, while the most common barrier is the way errors are dealt with.

Usage Patterns of Digital Media Technologies

In relation to table 16, While different technologies are used to different extents in different design phases, 2D + 3D CAD technologies are extensively used across all the different phases of the architectural design process. On the contrary, parametric design is the least used digital media technology. Overall, more than 50% of the work in the architectural design process is done using digital media, the highest being at the working / construction drawings phase at 58.36%

Different digital media technologies are prominently used in different architectural design phases. Image processing technologies are extensively used in the presentation /documentation phase ($c = 0.262$), while 2D + 3D CAD are mostly used in the design development phase ($c = 0.331$). Building information modeling technologies are highly used in the as-built documentation phase ($c = 0.25$), while parametric design tools are mostly used in the as-built documentation phase ($c = 0.112$) despite its minimal usage in the design process. Big data ($c = 0.276$), machine learning and artificial intelligence ($c = 0.32$), and building design simulations ($c = 0.261$) are all mostly used in the pre-design / analysis phase. Presentation and as-built documentation phases have the highest average extents of digital media usage, while working drawings and post-occupancy evaluation have the lowest. Further major findings include:

1. Image processing technologies are extensively used at various levels of proficiency.

2. Building information modelling has average usage extents combined with low familiarity. In combination with the fact that it is one of the most used technologies in the design process, this deduces that it is used a lot in the architectural design process but only to a limited extent of proficiency.
3. Machine learning + artificial intelligence technologies exhibit professional-centric tendencies. Meaning that they are mostly used with higher competence due to the technological barrier of entry.
4. The following are the highest correlations between digital media technologies and architectural design phases:
 1. Image processing & Presentation / documentation (0.262)
 2. 2D + 3D CAD & Design development (0.331)
 3. Building information modelling & As-built documentation (0.323)
 4. Parametric design tools & As-built documentation (0.112)
 5. Big data & Predesign / analysis (0.276)
 6. Machine learning + AI & Predesign / analysis (0.32)
 7. Building design simulations & Predesign / analysis (0.261)
5. Parametric design tools have the lowest usage patterns across the design process.

Level of Digital Media Diffusion

The level of diffusion of digital media technologies varies throughout the different phases of the architectural design process. Each digital media technology exhibits different behaviors regarding its diffusion. Additionally, the architectural design phase and the complexity of the design activities undertaken significantly impact the level of diffusion.

Overall, demographic data had no impact on the level of digital media diffusion. Additionally, design process phases were analyzed for future potential for diffusion. Post-occupancy evaluation had the highest potential (15.38%), followed by pre-design / analysis (12.72%) and the presentation / documentation phase (9.39%). A summary of additional prominent findings are as follows:

1. The comparative ranking of the diffusion of digital media technologies based on descriptive statistics are:
 1. Image processing
 2. 2D + 3D CAD
 3. Building information modelling
 4. Parametric design tools
 5. Big data
 6. Machine learning + AI
 7. Building design simulations
2. Parametric design technologies are used in abundance at basic levels and are rarely used as the main digital media technology of a project.
3. Big data technologies are used to facilitate communications and aren't used directly.
4. Building-related simulations are used as supportive technologies for particular tasks.
5. When assessing digital media diffusion in relation to architectural design process phases, it is deduced that both analogue and digital approaches are equally used in Saudi Arabia.

6. Working / construction drawings, as-built documentation, post occupancy evaluation, and presentation / documentation phases are all documentation-based phases that exhibit similar behaviors regarding the level of digital media diffusion.

Readiness of the Saudi Architecture and Building Production Sector

The Saudi architecture and building production field exhibits high levels of managerial and infrastructural readiness for digital media adoption and diffusion, while lacking in motivation and interpersonal factors that affect its readiness. Furthermore, readiness was concluded to be independent from digital media usage patterns and extents of usage. Most architectural design process phases exhibited positive readiness, except for as-built documentation. The highest levels of readiness were observed in the post-occupancy evaluation, pre-design / analysis, and the presentation / documentation phases; where readiness descends respectively. Further findings from the study are summarized as:

1. The Saudi architecture and building production sector experiences uncertain speculations regarding the usage of digital media technologies. Though sentiments are generally neutral, they can be positively or negatively affected by external factors.
2. The predesign / analysis phase is more reliant on digital media rather than human intervention.
3. The conceptual / schematic design phase is equally reliant on digital media and human intervention.
4. The design development phase includes the use of a wide range of digital media technologies to different extents.

5. Presentation / documentation is majorly reliant on digital media technologies. Human intervention can be phased out by the appropriate combination of digital media technologies.
6. Working / construction drawings are majorly digitalized design phase, even though efficiently adopted digital media technologies are limited.
7. Working / construction drawings, as-built documentation, and post occupancy evaluation exhibit similar behaviors as the presentation / documentation phase. This is because they are all documentation activities.
8. Documentation activities are the most likely to completely abandon human intervention and become exclusively digitalized.
9. The technical nature of a design phase and its need of accurate data are the two most prominent reasons for identifying opportunities for digitalization.
10. The documentation activities can be further split into two categories, ready for additional digital media adoption and unready. Presentation / documentation phases are ready, while working / construction drawings and as-built documentation aren't ready.
11. Predesign / analysis phase has high readiness due to the nature of the design activities that happen within it. They are mostly reliant on digital media to collect and analyze data.
12. Clients are more satisfied with digital media adoption and diffusion than employees because they only view the advantages without experiencing the complications introduced.

Qualitative Phenomena

Qualitative data showed high levels of agreement regarding various topics. It was identified that monetary factors and the technical skills of employees significantly affected the perspective towards digital media technologies and their usage. Additionally, stakeholders who don't interact with digital media were found to be more supportive of their usage and adoption. Furthermore, there is a palpable disconnect between employees and firm owners. The phenomena identified through qualitative methods of the study are as follows:

1. The aspects that drive digital media adoption the most in the Saudi architecture and building production sector are improved quality, increased efficiency, attracting talent, and finally enabling greater insights.
2. The aspects that hinder digital media adoption the most are the time and cost of training, lack of experienced employees, existing rigid workflow processes, and limited finances.
3. Engineers and architects are the least supportive stakeholders for digital media adoption, this is because they need to deal with all the issues that are introduced with the digital media technology.
4. Regulatory bodies are highly supportive of digital media adoption.
5. Encouragement for innovation and development is limited.
6. Sufficient resources are available to support innovation adoption. This means that although not encouraged, innovation and development is properly supported.
7. Innovation adoption positively affects morale.
8. As a continuation to the 6th point, innovations are also recognized and rewarded.
9. Adequate training is available when new digital media technologies are adopted.

Satisfaction with Digital Media

Finally, satisfaction with digital media was assessed in relation to multiple demographic categorizations. The results are as follows:

1. In relation to firm size, all firm sizes are extremely satisfied with digital media in the pre-design phase and the post occupancy evaluation phase. High satisfaction is seen in the presentation / documentation phase, while dissatisfaction is seen in the as-built documentation phase. Conceptual and schematic design phase and the design development phase show low satisfaction.
2. A similar pattern is seen in relation to the office type. The only difference is that working / construction drawings exhibit more positive satisfaction.
3. Assessing according to profession, the same pattern is seen. However, it can be seen that technical assistants have the highest satisfaction in design phases that tend to have high satisfaction levels, in addition to having relatively high satisfaction at the conceptual and schematic design phase. Additionally, architects and engineers share similar sentiments.
4. According to years of experience, the data exhibits interesting trends across the entire set. In addition to following the general trend like the other data sets, it can be seen that the presentation / documentation phase steadily increases as years of experience increase up to 11-20 years of experience, then drops back. The same behavior is seen at the working / construction drawings phase, but the peak is reached at 21-30 years. Additionally, individuals with 11-20 years of experience are on average the most satisfied with digital media technologies across the architectural design process. Individuals with 21-30 years of experience have abnormally highest satisfaction in working / construction drawings which is a low

satisfaction phase, while having the lowest satisfaction in post occupancy evaluation which is the highest satisfaction design phase.

5.3 Implications

The study provides an in-depth examination of several issues related to usage of digital media in the Saudi architecture and building production sector. Although further research is needed on this topic, the following suggestions appear to be appropriate at this stage:

- Level of adoption and usage of parametric design tools and big data technologies seems to be lower than developed countries. More efforts are needed to improve the adoption and level of use, while efforts are needed to realize the potential of the technologies despite their complexity and difficult learning curve. Furthermore, the usage of artificial intelligence and machine learning can be explored beyond basic usage.
- Architectural design phases like pre-design / analysis, presentation / documentation, and post-occupancy evaluation have comparatively notably high readiness for digital media adoption and diffusion. Research and development should be explored to further advance those phases using already prominent digital media technologies in those phases, namely machine learning and artificial intelligence, image processing, and 2D + 3D CAD respectively.
- As-built documentation phase was identified as a phase that has overinvestment in digital media technologies. Those resources can be reallocated into one of the aforementioned phases with high digital media adoption and diffusion readiness.

- Managerial and systematic restructuring can be explored to change the sentiments of architects and engineers towards the adoption of emerging digital media technologies.

The study categorizes and highlights areas of potential in the Saudi architecture and building production sector. Firstly, it analyzed the Saudi context and deductions were made to help elevate its usage of digital media technologies. This was done through participants feedback and then benchmarking it against different countries with similar characteristics. The implications state that the context of digital media innovation has an abundance of resources but no motivation for individuals and firms/organizations to innovate and to reach those supportive resources. Additionally, digital media technologies are championed for their benefits, but the drawbacks are seldom known. This is why the public supports digital media adoption while engineers and architects are against it. As regulatory bodies are extremely supportive of digital media adoption, regulations must be introduced to streamline the development and adoption processes.

Additionally, areas of overinvestment in digital media technologies were realized. Most notably the as-built documentation phase. In every metric used, it was either rated as being overly supported with digital media, or sufficiently with no need of further growth. On the other hand, phases like the predesign phase and the as-built documentation phase show high levels of potential and satisfaction, which makes reallocating resources to those phases more sensical.

Finally, to support those implications, specific digital media technologies were mapped onto specific architectural design processes. This helps the Saudi architecture and building

production sector to easily develop areas that require development with the appropriate digital media technologies. Those findings can be slowly introduced as guidelines into the field, gradually shifting focus and efforts into more efficient areas of development.

5.4 Future Research

This study raises many issues that are highly recommended to be addressed in future research. These issues are of two types, theoretical and methodological.

5.4.1 Theoretical

- The study points out the need to further study the digital media usage in the Saudi architecture and building production sector. Further work is needed to understand the appropriate focus for different ranges of digital media technologies on different parts of the architecture and building production field in Saudi Arabia.
- Analyzing the Saudi architecture and building production sectors based on market readiness analysis strategies.
- More research is needed to investigate micro contexts within Saudi Arabia, focusing on rapidly developing regions, regions with mega projects, and regions with major infrastructural projects.
- More studies are also needed to explore the usage of new media such as AI, and the readiness of Saudi market for its impact on the performance of the market.

5.4.2 Methodological

- Replicate the study using different qualitative and experimental research methods such as grounded theory, allowing for more in-depth data to be collected. Though extremely time consuming, such qualitative methods would yield more in-depth findings if they were the primary methods.

- Redesign the study to approach the Saudi architecture and building production field from a different perspective. This can be managerial, psychological, or through a time-based approach.
- Future research may focus on a singular independent variable, to acquire extensive comprehensive data about it. This can either be a particular design phase or a particular digital media technology.
- This research is correlational in nature. Future research can propose and test specific research hypothesis.

Appendix

A. Questionnaire Survey

Group 1: Demographic Questions.

Q.1 Name of firm/organization you are affiliated with?

Q.2 Number of employees in the (branch of the) firm/organization office you are working in?

Question type: Multiple choice.

- Under 10
- 11-50
- 51-100
- 101-200
- 201-500
- 501-1000
- Over 1000

Q.3 What is the license/category of the firm/organization you work in as per The Saudi Council of Engineers?

Question type: Multiple choice.

- Engineer Office
- Consultant Engineer Office
- Engineering Consultations Office
- Engineering support service offices
- Professional engineering companies

Q.4 The main work of the firm/organization you work in?

Select all that apply.

Question type: Checkbox.

- Architecture (design + consultation)
- Engineering (design + consultation)
- Construction
- Project management

Q.5 Your profession?

Question type: Multiple choice.

- Engineer (Civil, Structural, Mechanical, Electrical, Environmental, etc)
- Architect
- Building-related designer (landscape architect, interior designer, etc.)
- Technical assistant (CAD Operator, assistant architect, assistant engineer, etc)

Q.6 Years of experience in the architecture and building construction industry?

Question type: Multiple Choice

- Under 5
- 6-10
- 11-20
- 21-30
- Over 30

Q.7 What is your role in the decision-making process within the firm/organization?

Question type: Multiple choice.

- Employee with no administrative /decision-making role
- Owner/Partner

Group 2: Software/Technologies across design/work activities

Q.8 To what extent are you familiar with or have used the following building design software/technologies in your work?

1- Very unfamiliar, 7- Extremely familiar.

If completely unfamiliar, please choose "Not Applicable."

Question type: Matrix / Rating Scale

- Image processing (Photoshop, etc.)
- 2D + 3D CAD (AutoCAD, etc.)
- Building information modelling (Revit, etc.)
- Parametric design tools (Rhino, etc.)
- Big data (MongoDB, etc.)
- Machine learning + Artificial intelligence (ChatGPT, etc.)
- Building-related simulations (CFD, etc.)

Optional: Please state any other design-related technologies you are using in your work and were not mentioned or listed above, and state your familiarity with them (on 1 to 7 scale used above).

Q9 To what extent are the following building design software/technologies used in your firm/organization?

1- Barely used, 7- Extensively used.

If completely unfamiliar, please choose "Not Applicable."

Question type: Matrix / Rating Scale

- Image processing (Photoshop, etc.)
- 2D + 3D CAD (AutoCAD, etc.)

- Building information modelling (Revit, etc.)
- Parametric design tools (Rhino, etc.)
- Big data (MongoDB, etc.)
- Machine learning + Artificial intelligence (ChatGPT, etc.)
- Building-related simulations (CFD, etc.)

Optional: Please state any other design-related technologies you are using in your work and were not mentioned or listed above, and state your familiarity with them (on 1 to 7 scale used above).

Q10 List in a ranking order the most used building design software/technologies in your firm/organization.

Rank #1 indicates the most used software/technology, while rank #7 indicates the least used software/technology.

Question type: Ranking.

- Image processing (Photoshop, etc.)
- 2D + 3D CAD (AutoCAD, etc.)
- Building information modelling (Revit, etc.)
- Parametric design tools (Rhino, etc.)
- Big data (MongoDB, etc.)
- Machine learning + Artificial intelligence (ChatGPT, etc.)
- Building-related simulations (CFD, etc.)

Q11 List the most used building design software/technology in your firm/organization in each of the following building design activities?

Select all that apply.

Question type: Multiple text boxes.

- Pre-design / analysis
- Conceptual and schematic design
- Design development
- Presentation / documentation
- Working / construction drawings
- As-built documentation
- Post occupancy evaluation

Q12 In your opinion, what percentage of work is currently conducted in your firm/organization using computers, digital media, and related technologies in the following work activities?

The percentage describes the level of utilization of computers and digital media in the work process; where 100% means fully utilized and 0% means completely unutilized.

Question type: Matrix / Rating scale.

- Pre-design / analysis
- Conceptual and schematic design
- Design development
- Presentation / documentation
- Working / construction drawings
- As-built documentation
- Post occupancy evaluation

Q13 As a follow up to previous question, for work activities in which computers, digital media, and related technologies are underutilized (less than 50%), what are the possible reasons for such underutilization in your firm?

Question type: Checkboxes.

- The way errors are dealt with
- The existing nature and level of workplace collaboration
- Limited financial resources
- Laws or other governmental mandates
- Lack of technical skills needed
- Introduces a lot of unwanted change to the workflow
- Other:

Q14 As a follow up to previous question, for work activities that depend heavily on utilizing computers, digital media, and related technologies (50% or more), what are the possible reasons for such level of utilization in your firm?

Question type: Checkboxes.

- A lot of issues arise because of these particular activities
- Digital media packages already exist that introduce substantial improvements
- The activities are typically very time consuming without the utilization
- Mistakes in said activities are relatively costly
- Without utilization, data isn't accurate enough to be reliable
- Market competitiveness requires the utilization
- Other:

Group 3: Automation & Readiness

Q15 Given your experience in the Saudi building and construction field, to what extent can/should the following work activities be automated?

The percentage indicates the level of readiness of the market for full automation; where 100% means can be/should be fully automated and 0% means cannot be/should not be automated.

Question type: Matrix / Rating scale.

- Pre-design / analysis
- Conceptual and schematic design
- Design development
- Presentation / documentation
- Working / construction drawings
- As-built documentation
- Post occupancy evaluation

Q16 In the previous question, what factors affected your opinion regarding the potential/readiness of the Saudi building and construction market for automating various activities of work.

Select all that apply.

Question type: Checkboxes.

- Required accuracy of the data
- Technical nature of a phase
- Creative nature of a phase

- Cost of automation compared to human intervention
- Efficiency of workflow
- Technological Advancements
- Other:

Q17 In your firm/organization, please choose the level of work automation in each work activity.

Question type: Matrix / Rating scale.

- Pre-design / analysis
- Conceptual and schematic design
- Design development
- Presentation / documentation
- Working / construction drawings
- As-built documentation
- Post occupancy evaluation

Optional: What software/technologies are used to facilitate the automation?

Q18 In your firm/organization, how do you rate the satisfaction with work automation?

Question type: Matrix of Dropdown Menus (Completely unsatisfied – Completely satisfied)

- Client's perspective
- Employee's perspective

Q19 Which of the following factors drive the adoption of advanced building design software/digital technologies in your firm/organization?

Question type: checkboxes.

- Improved quality enabled by new technologies
- Increased efficiency in work (e.g. same results with fewer resources) enabled by new technologies
- Attracting excellent workers and employee interested in the valuable training and the improved professional growth available through exposing to new technologies in the field
- New technologies enables greater insights into the work tasks
- Increased accuracy and consistency enabled by new technologies
- More advanced work approaches enabled by new technologies
- Improved interdisciplinary and integrative work during design work enabled by new technologies
- Increased client satisfaction with services and work enabled by new technologies
- Other:

Q20 What are the factors that hinder/discourage the adoption of advanced building design software/digital technologies in your firm/organization?

Question type: Checkboxes.

- Limited financial resources
- The current/existing rigid workflow processes
- The time and cost of training needed for employee on the new technologies
- Lack of employee expertise in new technologies
- Uncertainty of return on investment
- the need to change/adapt current existing work procedures to fit new technologies

- Lack of interest of clients in new technologies or willingness to pay for the quality work produced

- Other:

Q21 Based on your experience in the Saudi market, please rate how supportive are the following stakeholders of the adoption of advanced building design software/technologies?

Question type: Matrix / Rating scale (completely unsupportive – completely supportive)

- Clients
- Architects
- Engineers
- Consultants
- Contractors
- Commissioning agents
- Building managers
- Regulatory & professional bodies

Group 4: Diffusion of innovation

Q22 To what extent do you agree with the following statements?

Question type: Matrix / Rating scale (highly disagree – highly agree)

- I am encouraged to be innovative or seek out better ways of operating.
- Resources (time, funding, personnel) are provided and managed efficiently in support of innovation.
- Innovation affects my morale positively.
- Innovations are recognized and rewarded.

Q23 What building design software/technologies does your firm/organization plan to buy and use in the next 2-4 years?

Question type: Single textbox.

Q24 What building design software/technologies your firm or organization have adopted and used in the past 1-4 years?

Question type: Single textbox.

Q25 What building design software/technologies has your firm/organization adopted and used before 5 years or more?

Question type: Single textbox.

Q26 To what extent has your firm/organization provided adequate training when it adopted and used new design software/technologies?

Question type: Matrix / Rating scale (No training – Complete comprehensive training)

Q27 If you would like to provide extra feedback, please do here.

Question type: Comment box.

B. Formulas

$$x = Z(c/100)^2 r(100-r)$$

$$n = N x / ((N-1)E^2 + x)$$

$$E = \text{Sqrt}[(N - n)x / n(N-1)]$$

Formula 1: Sample size calculation. Presets: n = sample size, E = margin of error, c = confidence level. Calculated: N = population size, r = fraction of responses needed, $Z(c/100)$ = critical value of confidence level

$$\chi^2 = \sum (O_i - E_i)^2 / E_i$$

Formula 2: Chi-Square (denoted by χ^2). O_i = observed value (actual value), E_i = expected value.

$$\text{cov}(X, Y) = \sum_{i=1}^N (X_i - \bar{X})(Y_i - \bar{Y}) / N$$

$$\rho_{X,Y} = \text{cov}(X, Y) / \sigma_X \sigma_Y$$

$$\rho_{X,Y} = \sum_{i=1}^n (X_i - \bar{X})(Y_i - \bar{Y}) / \sqrt{\sum_{i=1}^n (X_i - \bar{X})^2} \sqrt{\sum_{i=1}^n (Y_i - \bar{Y})^2}$$

Formula 3: Sample Correlation Coefficient (denoted by $\rho_{X,Y}$), X and Y = two random variables, N = population size, cov = covariance, σ_X = standard deviation of X , σ_Y = standard deviation of Y .

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