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Cloud Computing in the Construction Industry

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ABSTRACT

Cloud computing (CC) is a general term for anything that involves delivering hosted services over the Internet. It delivers computing services, including servers, storage, databases, software, networking and analytics, over the Internet ('the cloud'). It has emerged as a revolutionary technology that has transformed various sectors, including the construction industry. The uprise of cloud computing and smart technology is beginning to change everything about how construction is done, from beginning to end. This paper investigates the extent to which cloud computing has been used in the construction industry.

KEYWORDS: *technology, cloud computing, construction industry*

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INTRODUCTION

Cloud computing (CC) is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned. It just means storing and accessing information over the Internet rather than being tied to a computer's physical hard drive. Cloud computing technologies have revolutionized several industries including construction.

Construction is one of the oldest industries and it is also one of the most labor-intensive ones with more obligations. Yet, the construction industry has been notoriously slow to enter the digital era. Although the construction industry is well placed to leverage CC technologies for competitive and operational advantage, the diffusion of the technologies in the industry follows a steep curve. The construction industry is a very traditional sector. Figure 1 shows a typical construction site [1], while Figure 2 shows some construction workers [2]. Construction companies can streamline their operations and achieve greater efficiency through the use of cloud-based solutions, including project management tools, BIM platforms, and mobile applications.

CLOUD COMPUTING BASICS

Cloud computing represents a newly emerging service-oriented computing technology. It is the provision of scalable computing resources as a service over the Internet. It allows manufacturers to use many forms of new p systems such as 3D printing, high performance computing (HPC), industrial Internet of things (110T), and industrial robots. It is transforming virtually every facet of modern manufacturing. It is innovating, reducing cost, and bolstering the competitiveness of American manufacturing [3].

The key characteristic of cloud computing is the virtualization of computing resources and services. Cloud computing is implemented in one of three major formats: software as a service (SAAS), platform as a service (PAAS), or infrastructure as a service (IAAS). These services are illustrated in Figure 3 [4] and explained as follows:

SaaS: This is a software delivery model in which software and associated data are hosted on the cloud. In this model, cloud service providers offer on-demand access to computing resources such as virtual machines and cloud storage. Nowadays oil & gas companies transition to cloud computing and implement SaaS solutions for operations.

PaaS allows the end-user to create a software solution using tools or libraries from the platform service provider. In this model, cloud service providers deliver computing platforms such as programming and execution.

In the laaS model, cloud service providers can rent manufacturing equipment such as 3D printers.

Just like cloud computing, CM services can be categorized into three major deployment models (public, private, and hybrid clouds) [5]:

- Private cloud refers to a centralized management effort in which manufacturing services are shared within one company' or its subsidiaries. A private cloud is often used exclusively by one organization, possibly with multiple business units.
- Public cloud realizes the key concept of sharing services with the general public. Public clouds are commonly implemented through data centers operated by providers such as Amazon, Google, IBM, and Microsoft.
- Hybrid cloud that spans multiple configurations. and is a composed of two or more clouds (private, community or public), offering the benefits of multiple deployment modes.

These models are shown in Figure 4 [6]. Cloud computing finds application in almost every field.

CLOUD COMPUTING IN CONSTRUCTION

Cloud computing refers to the delivery of computing services, such as storage, processing power, and software applications, via the Internet. It allows you to access everything from your computer, tablet, or phone because it is all stored on the cloud (that is, on the Internet) and you can access your files from anywhere. The majority of construction work must be done at construction sites, the plant, the roads, and everywhere else in between. The construction industry is well-positioned to benefit from the CC technologies for operational and competitive advantages, but their widespread adoption follows a steep trend. As construction projects become increasingly complex, demanding seamless collaboration, efficient project management, and secure data storage, cloud computing offers a multitude of benefits and solutions. By integrating CC technologies, construction companies can enhance productivity, streamline processes, and achieve unprecedented levels of efficiency.

The use of cloud computing in the construction industry is a relatively recent development. Cloud computing in construction industry has become an active area of research evidenced by the soaring interest in the field. Cloud computing used in the construction industry has several models: private cloud, public cloud, and hybrid cloud. Public cloud is the most widely used cloud computing model. Examples of new business models for construction that could emerge include design-as-a-service, procurement–as-a-service, construction-as-a-service, facility management-as–a–service, demolition-as-a-service, retrofitting-as-a-service, waste management-as-a-service. Construction will thus be conceived as a utility and paid for per usage. Figure 5 shows cloud computing in construction [7]. Cloud service providers create massive data centers containing hundreds of thousands of computers employed virtualisation technology fortified with redundant power, networking, and connectivity. Popular cloud providers include Amazon, Google Inc., Microsoft Corp, Salesforce, Procore, CDC Software, APTEAN, and Oracle.

APPLICATIONS OF CLOUD COMPTING IN PHARMACEUTICALS

Cloud computing can be applied to the construction industry in various aspects, including but not limited to architectural design, structural analysis, cost estimating, project planning and control, and procurement management. Cloud computing is used at different stages of the project life cycle, which include feasibility, design and construction stages. It is widely used in the construction industry for a variety of purposes, including project management, data storage, and collaboration. Figure 6 displays some applications of cloud computing in construction industry [8]. Common areas of applications of CC in construction include the following [8]:

- *Waste Management:* The construction industry can have a negative impact on the environment, with a staggering amount of materials and resources going to waste. Uncoordinated construction management is characterized with untimely feedback that results in wastage of resources. Wastage throughout the life cycle of a building must be minimized to reduce project cost and time over run. It has been observed that limited accessibility to existing construction information has resulted in resources wastage. Thus, there is a need for cloud computing to

reduce transaction costs and enhance online collaboration tools.

- *Safe Construction:* Construction sites are usually dangerous due to a large number of workers, materials, equipment, and dynamic/unforeseen circumstances. The risk of working in the construction site is further increased by a lack of access to real time safety information to provide predictive, quantitative, and qualitative measures allowing the identification, correlation, and elimination of hazards and safety incidents. Cloud technologies are being employed to provide timely access to safety information and in turn resulting in improved safety performance of construction sites. Existing manual construction-safety monitoring is labor-intensive and error-prone. Thus a SaaS application is developed to detect unsafe conditions and analyze the trajectories of workers with respect to potential safety hazards on construction site.
- *Energy Management:* Buildings consume appreciable amount of energy during both construction and operation stages. Cloud computing has been employed to effectively manage energy in various stages of construction. The SaaS cloud has been proposed as an energy management system for sustainable decision support.
- *Supply Chain Management:* The existing uncoordinated traditional material supply in construction site usually resulted in supply gap leading to delay in projects**.** The public and private SaaS cloud platform has been employed for interoperability to bring together different stakeholders in the procurement process for efficient construction process.
- *Project Management Informatics:* The construction industry is characterized with communication and coordination problem culminating in low construction quality. Cloud computing technology for collaborative design will result in improved design, construction and project efficiency. The public SaaS cloud has been employed to formalize the transfer of knowledge among local construction companies to improve the construction project.
- *Collaboration:* In today's fast-paced world, construction projects have become more complex than ever before, requiring collaboration across different teams. Construction projects are executed by several project teams, with different business reporting models that are stored in different silos. Cloud computing enables construction teams to collaborate more effectively by enabling team members to access and share files and data in real time from anywhere with an Internet connection. The cloud makes it possible for everyone to be on the same page, no matter where they are. The word "team" has taken on a whole new meaning in the construction industry. Every team needs to obtain a high level of transparency and accountability for the property owner. Today's construction professional needs to be highly collaborative. Construction companies will be more collaborative, using technology to connect all project team members in one central location. By collaborating together on cloud platforms, construction stakeholders can store and receive construction data in real time.
- *Security:* Cloud computing providers have robust security measures in place, protecting data from loss or theft. Cloud security has matured and popular security measures in the cloud includes; encryption, use of up-to-date security software, cyber insurance security cover, security audit, and so on. Cloud service providers implement advanced security measures and best practices to ensure the safety of data stored in the cloud. This includes encryption, multi-factor authentication, and disaster recovery solutions. This way, companies avoid costly data breaches and other security issues. Cloud computing makes it easy to store fire safety plans, OSHA regulations and other important information in a central location so that everyone can access it at all times.

BENEFITS

The exploitation of cloud computing in construction project management has several advantages. The specific advantages of CC such as scalability, streamlining data resources, inclusive maintenance, etc. that make it an interesting concept for usage with the construction industry. CC helps to reduce costs, improve efficiency, collaboration and return on investment for developers and architects. Other benefits include [8,9]:

- *Back-office Functions:* These functions include billing, paying invoices, running financial reports, payroll, and planning logistics. They may have required physical presence on construction sites and are made possible using cloud computing. With remote access, construction sites are decentralized, while workers can work from various areas of the nation or even globally.
- *Sustainability:* Cloud computing adoption by construction companies is a great move towards a green society or a sustainable environment. Using cloud computing, construction companies can

reduce their carbon footprint by eliminating the need for physical storage space and reducing paper usage. This can help them achieve their sustainability goals. This makes it so that both the customer and the contractor can feel good about their project's environmental impact without sacrificing efficiency or quality.

- *Improved Quality:* The quality of construction projects has come under scrutiny in recent years, with some high-profile failures leading to costly lawsuits. In the past, teams have had to rely on paper-based systems to track quality data. This reliance on paper tracking has led to errors and inconsistencies that employees have a difficult time correcting. With the cloud, all data is stored in a single, easily accessible location, making it easier to spot and fix any problems. Cloud computing can help improve the quality of your jobs by making it easier to track and compare data.
- *Accessibility:* The most useful feature of the cloud is that it is accessible from anywhere, anytime. Cloud computing enables remote access to data, making it easier for teams to work from different locations. It allows you to view job sites from anywhere. Using aerial photos or drone footage, cloud computing lets stakeholders view job sites from anywhere. This can help them better understand the project's progress, identify potential issues, and make informed decisions. For companies with various ongoing projects, the ability to access paperwork and information without being bound to a desk can save a lot of time and many trips back to the office.
- *Flexibility:* Cloud computing allows construction companies to access their data and applications from anywhere with an Internet connection, making it easier to work remotely and helping construction companies with geographically dispersed teams or those needing to work on-site at different locations.
- *Cost Saving:* Cost is a significant barrier in the adoption of IT solutions by construction companies, because of its low-profit margin. Construction companies are seeking new ways to drive down infrastructure and operational costs. Cloud computing offers construction companies the opportunity to reduce both hardware and software expenses. By eliminating the need for extensive on-site infrastructure, significant capital investments can be saved. Cloud computing technologies have therefore provided opportunity to construction businesses especially SMEs to have access to high end computing infrastructure and applications which could cost a fortune to acquire. This will also undoubtedly translate to a reduction in the total cost of a project delivery, therefore giving construction companies a competitive advantage and operational edge.
- *Competitive Advantage:* A smaller construction company could find it difficult to compete with the giants of the industry, but such small companies could get a competitive edge with the help of cloud. Through cloud computing, even a small firm can achieve enterprise-level of recovery, management, access, and data storage at a fraction of the cost spent by bigger enterprises.
- *Scalability:* Cloud computing allows construction companies to scale their resources up or down as needed, making it easier to manage fluctuating workloads. Cloud computing enables a construction company to purchase IT resources as services dictated by the specific requirement at that particular period on a construction project. Cloud computing offers high-performance servers with powerful CPUs, GPUs, and super-fast SSD drives to construction industries at affordable prices.
- *Massive Storage:* Massive data generation characterizes construction projects, right from the design stage. The use of emerging technologies like artificial intelligence, IoT, Augmented reality, BIM generates continuously large data. For example, an aerial imagery of a site that will occupy points on a cloud storage, will take hundreds of GBs on a typical computer. Storing construction data on site requires physical access, whereas with cloud storage, data can be remotely stored and retrieved with no limitation to space and time. Hence the availability of cloud storage is an excellent opportunity for the construction industry.
- *Improved Project Management:* Cloud computing offers a centralized hub for storing and accessing project data, ensuring that all stakeholders can access the most current information. Cloud-based project management tools facilitate efficient scheduling and resource allocation, optimizing the utilization of labor, equipment, and materials. Real-time updates and notifications enable project managers to make timely adjustments, reducing downtime and maximizing productivity.

CHALLENGES

Although CC has brought about a revolution in the construction industry, it comes with its own set of challenges and limitations. There are also some adverse issues that the CC technology proponents

need to address before the commercial world at large will be comfortable in its adoption. Some of these issues include trust, security, interoperability, and migration cost. No doubt, some construction applications characterized with fast processing and quick response time may not be able to rely on the distant and centralized cloud computing. Other challenges include [8,10]:

- *Resistance to Change:* Transitioning to cloud-based systems may require training and efforts in change management to familiarize employees with new tools and processes. It is important to address any resistance to change from stakeholders who are accustomed to traditional methods during the implementation phase.
- *Legacy Systems:* A legacy system is an older or outdated technology or software application that continues to be used because it still has value to the organization and functions as it was originally intended. Migrating data from legacy systems to the cloud and integrating existing systems with cloud-based solutions can be complex and time-consuming. Construction companies should carefully plan their data migration and integration strategies to minimize disruptions and ensure a seamless operation.
- *Interoperability:* Cloud vendors will have to adopt standards-based technologies in order to ensure true interoperability. Interoperability issues present themselves in different forms both at the system as well as information and data levels. Thus, the interoperability issue in a cloud computing model is more complicated in context. Cloud environments that are neutral to programming languages and operating systems are desirable. Interoperation among applications should be allowed inside a single cloud environment. This requires connectivity of the applications as well as semantics alignment of the data exchanged among the applications.
- *Threats:* There are threats to cloud-based computing technologies that may hinder the efficient adoption of cloud-based computing technologies in construction project delivery. Construction stakeholders find them significant to hindering the successful integration in the construction process. The main threats to the use of cloud-based computing technologies can be categorized into security threats and connectivity threat.
- *Latency:* Cloud adoption in construction may not guarantee acceptable transfer rate and response time required for some time sensitive construction applications. This could either be a software issue or network problem. Construction companies may avert delay by choosing service providers with closer data centres as fewer hops between the service provider and the customer. Overcoming latency and some barriers in cloud adoption will facilitate seamless connectivity that could evolve a real-time collaborative practice leading to collaborative computing. Figure 7 depicts categories of factors that cause construction delays [16].
- *Data Privacy:* There are concerns about data ownership and privacy in cloud computing, particularly when it comes to sensitive project data. The anticipated vulnerability in the adoption of cloud technology is increasing due to the increasingly fluidity of the security perimeter. In practice, business partners are usually unwilling to give their private and commercial information such as project cost to a third-party.
- *Data Availability:* It is not uncommon to experience down time with technologies utilizing cloud resources, as a technology cannot be perpetual. A cloud provider may have cause to shut down their resources unexpectedly. The building data thus becomes unavailable, what will become of the building data? To overcome this concern, the cloud providers are known to provide 99.999% availability as stated in the Service Level Agreement. This is to allow exchanging data between clouds providers to avoid the issue of lock-in if a provider became unavoidably unavailable.
- *Data Governance:* Since construction projects usually involve many professionals, there is the need to spell out the contractual relationship between stakeholders. This is critical since the data is being contributed, it may be regarded as being owned by all. The issue of actual owner of data may arise, since all concerned party has access to the data and are required to update data continuously. The relationship between the building team members is also another point to consider.
- *Poor Connectivity:* Access to cloud services is primarily over the Internet, hence, to maximize the benefit of cloud solution in the construction site, Internet connectivity must be available every time. The reliance on Internet connectivity for cloud-based services can pose a challenge, especially in remote construction sites that have limited access to reliable internet connections. To minimize disruptions caused by Internet outages, construction companies need to ensure they have

alternative connectivity options or offline capabilities. Poor network connectivity is among the threats to cloud adoption by construction industry. Project sites at times might be an underdeveloped area or a rural area usually with low or no Internet connectivity.

- *Cost:* Accumulated cost for the use of cloud infrastructure over a long period could be daunting, depending on the type of deployment. Cloud SaaS pricing at inception was initially per unit time of consumption, further efforts by cloud researchers incorporated market value and brought about personalized pricing resulted in many pricings offers. The cost implication is not the same for the various cloud deployments types even for the same construction company. There could be substantial high cost of renting high-end resources such as GPUs for performing project analytics and machine learning tasks. Cost flexibility offered by cloud computing allows construction SMEs operating on tight budget to avoid significant upfront investment and operational cost.
- *Compatibility*: Cloud computing requires a certain level of technological sophistication, and not all construction companies may have the necessary infrastructure or skills to adopt it.
- *Data Security*: Security concerns are a common cause of hesitation about transferring data to the cloud. It can feel like you are uploading a lot of sensitive information such as intellectual property, plans, drawings, or financial data available for everyone to find online. Breaching a client's on-premise systems was generally easier than accessing their cloud-based data. You can ensure that no one can access your data unless you permit it by allowing access only to authorized users with unique login credentials.
- *Complexity:* Construction projects are getting increasingly complicated. As teams need to account for progressively complex planning and designing, the number of parties involved and stakeholders multiply from one project to the next. Construction companies are uniquely oriented to benefit from the cloud's ability to provide greater freedom and ease to access information anytime, anywhere.

CONCLUSION

Cloud computing has emerged as a transformative force in the construction industry, offering countless benefits such as cost savings, improved collaboration, and enhanced project management. It will result in emergence of new business models which will enable construction companies to do business in a new way. Almost as many concerns about abandoning traditional methods are in favor of the cloud. As the technology continues to evolve, we can expect to see further innovations in data management and collaboration. Implementing cloud tools could put you one step ahead of the competition.

In recent years, the interest in cloud solutions in construction has been booming.

In spite of challenges such as limited Internet connectivity and resistance to change, the future of cloud computing holds a bright future for the construction industry. More information about cloud computing in construction can be found in the books in [12,13].

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Figure 1 A typical construction site [1].

Figure 2 Construction workers [2].

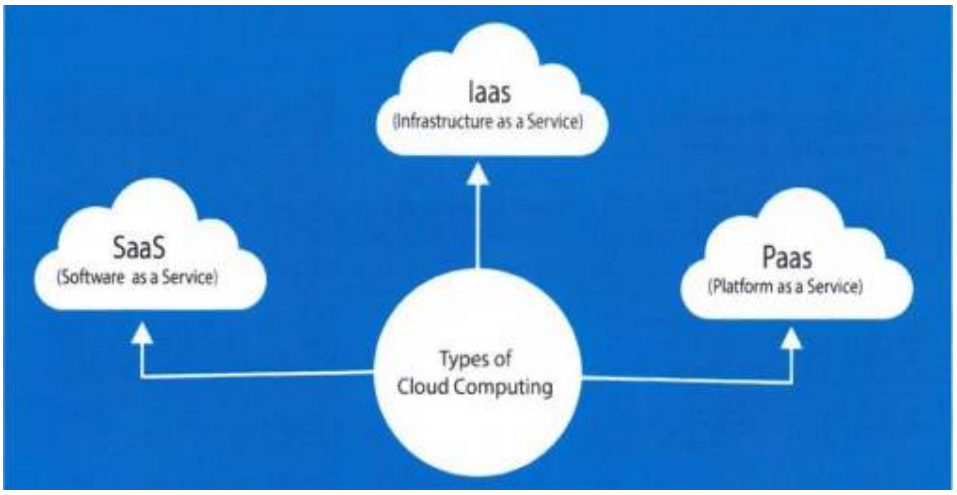

Figure 3 Three types of cloud computing services [4].

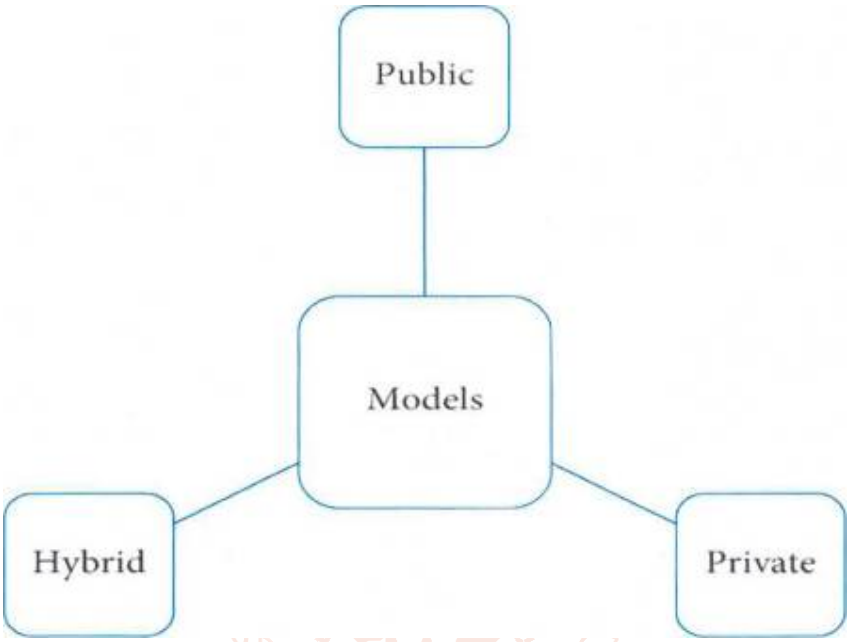

Figure 4 Cloud computing models [6].

Figure 5 Cloud computing in construction [7].

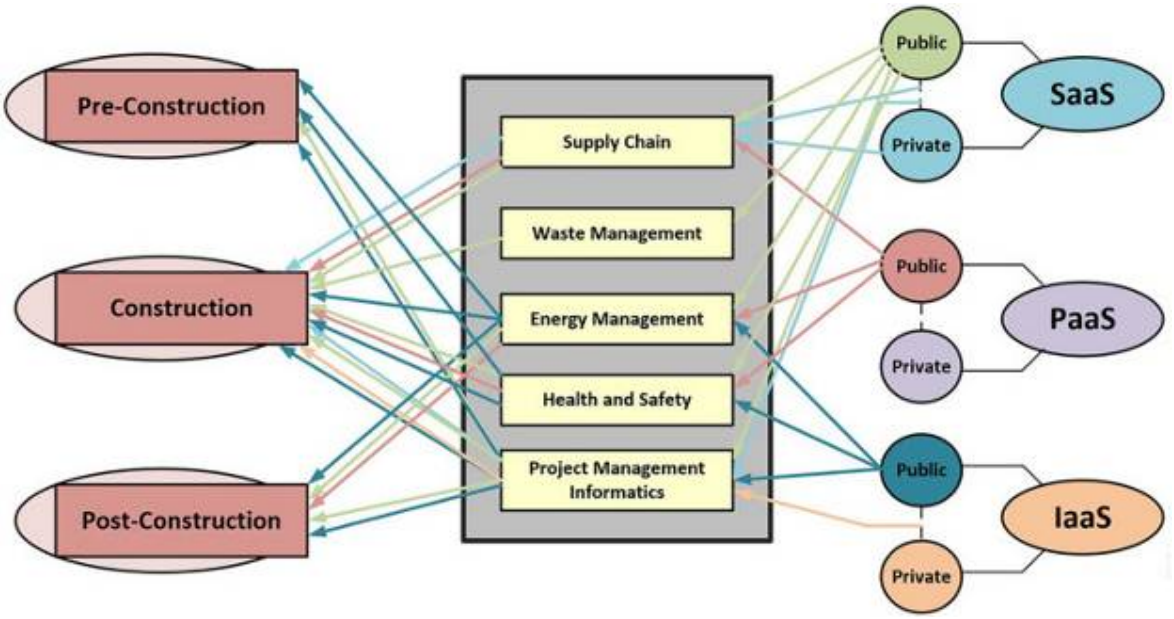

Figure 6 Some applications of cloud computing in construction industry [8].

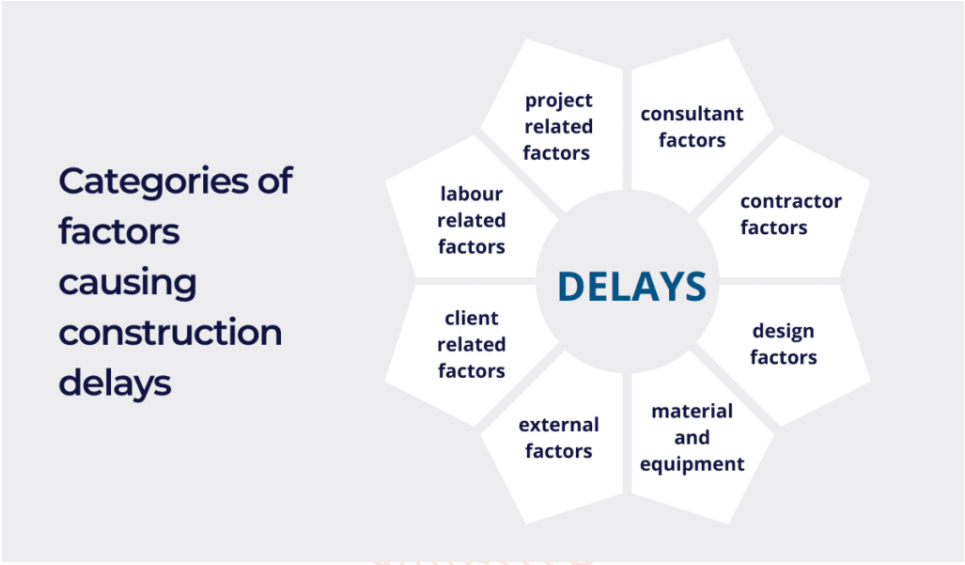

Figure 7 Categories of factors that cause construction delays [11].