Modularization in Gas Processing Facilities [1]

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Abstract

The escalating demand for natural gas has intensified the focus on construction-optimizing methodologies, with project management emerging as a pivotal concept. Drawing inspiration from the theory of Scientific Management, which emphasizes efficiency and systematic approaches, the study investigates the application of these principles in modular construction. The case study of Jafurah Gas Plant Project exemplifies this approach. This research underscores the importance of merging project management principles and Scientific Management theory to enhance efficiency in modular construction.

Key words: *Modular Construction***,** *Scientific Management***,** *Jafurah Gas Plant Project***,** *Natural Gas*

Introduction

Due to increased population growth, the demand for energy, particularly clean energy is at an all-time high. The increasing demand for energy has led to a proliferation of LNG liquefaction plant projects around the world. Liquefied natural gas (LNG) emerges as a pivotal factor in this scenario. Gas processing facilities are constructed in the world to tap into various gas production companies around the world; however, stakeholders invariably seek safe and effective solutions to cut costs and alleviate schedule delays. Offshore and onshore gas plants are challenging to construct on a tight project schedule, and this has necessitated the incorporation of modular projects. Modularization is a new method of construction that has revolutionized the way construction is carried out. To put it in simple terms, think of the change that would take place if there was no road traffic on your way to work; your travel time will be less. This is basically the modularization technique in the world of construction. In a broad definition, modularization is a construction technique where all components of a module are pre-assembled in an offsite location and then transported as one complete product to the process area. In this method, structural steel, equipment, piping, electrical, and instrumentation work are executed in distinct modules, which are then transported to the site for installation. Modularization, hence, emerges as a capable strategy of

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controlling costs, mitigating project schedule risk, and enhancing overall safety and quality performance (Castorani et al., 2018). The method can add many advantages to the project such as ability of parallel construction activities between site and modular yard, increase of manpower and equipment to maximize productivity, better quality assurance and reduces safety risks. While modularization poses heightened logistical concerns for transportation and materials delivery, early stakeholder alignment, detailed planning, and comprehensive coordination mitigate these challenges. Despite its effectiveness, many contractors are still struggling to successfully implement it in their projects. This study supports contractors to understand the modularization technique in terms of best practice implementation and overcoming its challenges, and how far it aligns with project management approaches of cost cutting and project schedule optimization.

Research Question and Hypothesis

The research question guiding this study is: "*To what extent does the application of modularization enhance efficiency and cost cutting outcomes in the gas processing facilities?* By exploring this question, this research aims at highlighting how the systematic application modularization in gas processing facilities enhances the efficiency, quality, and cost-effectiveness of a gas facility project that aligns with the principles of Scientific Management. It is proven that by adhering to these principles, modular construction processes will demonstrate shorter assembly times, reduced costs, higher quality control, and improved overall project outcomes. The paper examines Jafurah Gas Plant Project located in the Eastern Region of Saudi Arabia as a case study to answer the research question.

History of Modularization in the Construction Industry

The history of modularization in the construction industry is a journey marked by innovation, efficiency, and transformative change. Dating back several decades, the roots of modular construction can be traced to the mid-20th century (Bertelsen, 2005). In the post-World War II era, there was a surge in the need for rapid and cost-effective construction solutions to address the widespread demand for housing and infrastructure. This necessity laid the groundwork for the development of modular construction techniques. Initially applied in residential construction, modular methods gained traction for their ability to streamline processes and accelerate project timelines (Bertelsen, 2005). When the construction industry began evolving, modularization became an integral part of the construction process extending far beyond the residential project.

The 1960s witnessed a renewed emergence of modular construction especially in the commercial and industrial settings. The concept of using prefabricated components produced in off-site areas and then later assembled on the site became quite popular as a result of efficiency, lowered construction time as well as their cost effectiveness (O'Connor et al., 2015). One of the industries that played a critical role in enhancing this technology was the oil and gas industry. The construction of large-scale projects such as refineries and chemical plants strengthened the wide scale adoption of modularization. The shift in its adoption was heavily fueled by the fact that modularization showcased great versatility and was adaptable to a wide range of projects (O'Connor et al., 2016). Later in the 20th century, modular construction techniques were further enhanced by the advancement in new technologies; for example, the use of Computer Aided design (CAD) played a critical role in helping contractors to fabricate modular components using this software thus ensuring easy integration at the site.

The 21st century has marked a new age for modularization, which is heavily supported by advancements in materials, logistics and project management strategies. The construction industry has fully embraced modularization approaches with a key focus on tackling some of the key challenges such as labor shortages, project delays and cost overruns (O'Connor et al., 2014). In recent times, the modular approach became an integral part of the healthcare and hospitality industries since the focus was creating standardized and efficient solutions. Since then, modularization has become a cornerstone of modern construction initiatives whereby new projects showcase that it can be further enhanced to achieve the best results.

Wide Scale Adoption in the Oil and Gas Industry

Since its inception, modularization has been heavily incorporated in the oil and gas industry pushed by the need to acquire efficiency and flexibility. During its early days, project managers constructed monolithic structures, which created huge issues especially for expansion and maintenance (Bondi, et al 2016). However, during the 1970s and 1980s, modularization took a stronghold of the industry as the industry sought to lower the overall costs and lead times. To support this shift, technological innovations played an integral role in creating more feasible modular designs. For example, the enhanced standardization of integral components such as compressors and separators led to the pre-fabrication of modular units (Bondi et al., 2016). Similarly, the quest to undertake offshore gas production and exploration strengthened the adoption of modularization in the industry. This is because prefabricated modules could be transported to remote locations, therefore, reducing the costs and time required to complete the same on the site.

The reasons for the adoption of modularization in the gas industry is multifaceted. On one hand, project managers argue that modularization is cost effective. Standardizing components lead to mass production, which takes advantage of the economies of scale. The modular designs are scalable and flexible making it possible for organizations to add or remove modules in response to the demand in the industry. This often leads to a highly agile and responsive project (Halker, 2015). Another reason for the adoption of modularization in the gas industry is the fact that this approach is safer. This is because organizations can execute the modules erection and fabrication in a controlled environment where safety standards can be easily monitored. In addition, the conflict between contractors on planning the site activities is not applicable in the modular construction, which increase the safety implementation. In the gas industry, safety remains a top priority to prevent on-site accidents; and since modularization fosters parallel construction, it reduces the risk of such accidents.

Technologies Fueling Modular Adoption

Today, the adoption of modularization in the gas industry is fueled by the incorporation of cutting-edge technologies. These new technologies not only enhance the design, they foster efficiency and precision, limiting concerns for errors. Some of the key technologies being used today include 3D printing. Perhaps the biggest technology that is expected to dominate the modularization landscape is the incorporation of 3D printing (Teizer et al., 2019). Using this technology, project managers are able to create intricate and customized components relying on enhanced precision. This eventually leads to the creation of highly specialized modular units (Teizer et al., 2019). The incorporation of 3D printing not only accelerates the production process, but it enhances structural integrity and performance leading to the creation of high-quality gas sites.

Another integral component of modularization is the concept of automation and data analytics. In this case, many project managers are relying on automated assembly lines to create the modular units. This approach not only enhances consistency and accuracy, it leads to reduced construction timelines (Tak et al., 2020). The approach seeks to reduce human error and enhance safety leading to the creation of high-quality modular projects. Similarly, in an era where modularization in the gas industry is fueled by a concern for environmental protection, these designs help project managers to achieve that. Modular designs are resource efficient, which ultimately leads to reduced ecological footprints. In most modular construction sites, there is a growing adoption of eco-friendly materials, efficient energy systems that have minimal waste (Kamali & Hewage, 2017). Using this approach is further enhancing the sustainability of the gas industry since it pushes them to align with aligning to the regulatory requirements.

Literature Review

Innovative Practice in Modularization

The modern landscape in modularization is marked with a unique blend of practices and approaches that contribute to the project efficiency, sustainability and innovation. In the gas industry, recent modularization efforts depart from the traditional constructions with a key focus on off-site fabrication of the construction components within a controlled environment. The reason of shifting from the traditional concept to the modular one is the difficulties and challenges the project management teams have been experiencing in the execution of offshore or onshore mega projects. When there are more than 30 contractors with their subcontractors working on site, the planning of activities becomes very difficult. Each contractor is under pressure to achieve their progress target, while at the same time they face difficulties among working with each other. For example, access of mobility equipment for the structural contractor is not feasible due to slow progress of backfilling the excavated area by the civil contractor. The stress on the contractors increases and the cost impact arises where the deadline for handing over the project is not met. To solve all those difficulties, the modular technique is implemented.

As a self-innovated practice, the owner of the project shall evaluate the work of the contractors and assign an offsite location for each contractor that has an interface percentage of more than 50% with other contractors. In other words, if the structural contractor cannot start steel erection until the civil contractor completes the installation of concrete foundation and backfilling the area, the structural team shall be assigned to an offsite location to carry on their activities. An interface formula can be established at the beginning of each project to understand the impact of contractors' progress among each other taking into consideration the other factors as well, such as the associated cost of transporting the module back to site.

According to Zhang et al. (2020), this approach ensures precision and supports parallel activities leading to a reduced project timeline. Many gas mining companies have adopted modularization to optimize their resources and enhance the project outcomes (Bondi et al., 2016). Various studies have showcased the widespread adoption of advanced technologies such as Building Information Modeling (BIM) and Computer-Aided Design (CAD). Due to the precise nature, these technologies allow for the seamless incorporation of prefabricated modules into the existing design. This is a good strategy since it tackles some of the on-site challenges that can interfere with a project**.**

Emerging Trends in Modularization

Due to the wide adoption of modularization in the gas industry, there has been an emergence of new trends that shape the way projects are conceptualized and completed. One prominent trend is the increasing focus on sustainability (Mancini et al., 2016). Modular construction inherently promotes sustainability by minimizing material waste, optimizing energy consumption, and offering opportunities for recycling and reusing components. The materials waste during pre-fabrication is minimal due to the high accuracy of designing.

Another notable trend is the customization of modular components to suit specific project requirements. Modularization, once seen as a standardized approach, is evolving to accommodate the unique needs of diverse projects (Mancini, et al., 2016). This trend aligns with the growing recognition that one size does not fit all in the realm of construction, especially in complex sectors such as gas processing facilities.

Secondly, the integration of off-site manufacturing hubs and the use of advanced robotics and automation represent yet another trend in contemporary modular practices. These technologies enhance the precision, speed, and quality of module fabrication, addressing concerns related to human error and variability (Pan et al., 2022). Despite the positive trajectory, challenges persist in the modularization landscape. Transportation logistics, module size limitations, and the need for standardized interfaces are among the challenges that researchers and practitioners grapple with. Understanding these challenges is crucial for developing strategies that optimize the benefits of modularization while mitigating potential drawbacks.

Theoretical Underpinning

Although Scientific Management Theory originated in the context of manufacturing, its underlining principles are relevant to the modern construction industry. Developed by Frederick Taylor in the early 20th century, the theory focuses on optimizing efficiency and productivity through systematic observation, analysis, and data-driven decision-making. In Scientific Management theory, Taylor introduced time and motion to evaluate the most efficient ways to undertake tasks. The theory emphasizes the standardization process in the construction industry because it fosters maximum efficiency. In today’s construction industry, the major focus is on cutting construction costs and reducing time (Maskuriy et al., 2019).

Case study: Jafurah Gas Plant Project

One of the best examples of the recent advancements in modularization is the Jafurah Gas Plant project under the Unconventional Resources program. The unconventional resources program is a series of projects to be undertaken within the Kingdom of Saudi Arabia under Saudi Aramco's Portfolio. The development of the Jafurah unconventional gas field is one of the most ambitious projects in Aramco's history. It is the largest unconventional gas field with an estimated 200 trillion standard cubic feet of gas in place with the Jafurah basin hosting the largest liquid-rich shale gas play in the Middle East. This shale play covers an area measuring 17,000 square kilometers and production of natural gas at Jafurah is expected to ramp up from 200 million standard cubic feet per day (scfd) in 2025 to reach a sustainable gas rate of two billion scfd of sales gas by 2030, with 418 million scfd of ethane and around 630,000 barrels per day of gas liquids and condensates, which are essential feedstock for the growing petrochemical industry (Gray, 2022). The unconventional resources program is divided into several projects such as gas processing trains, industrial support facilities and site development, export pipeline and utilities. As all the packages are equally important, the more complex package is the gas processing trains package. In this case study, the analysis focuses on the implementation of modular concept in Gas Processing Trains Project. As a start, the scope of the project is to build two identical gas processing trains (South& North). This includes steel structure pipe racks, static and dynamic mechanical equipment, under and above ground piping, electrical supply, instrumentations and civil activities. As seen in Figure 1, the middle long Piperack will be built using a stick-built method while the four connected pipe racks (on the side of the middle one) will be built using modular construction and then transported to site to have a final shape as shown in Figure 1.

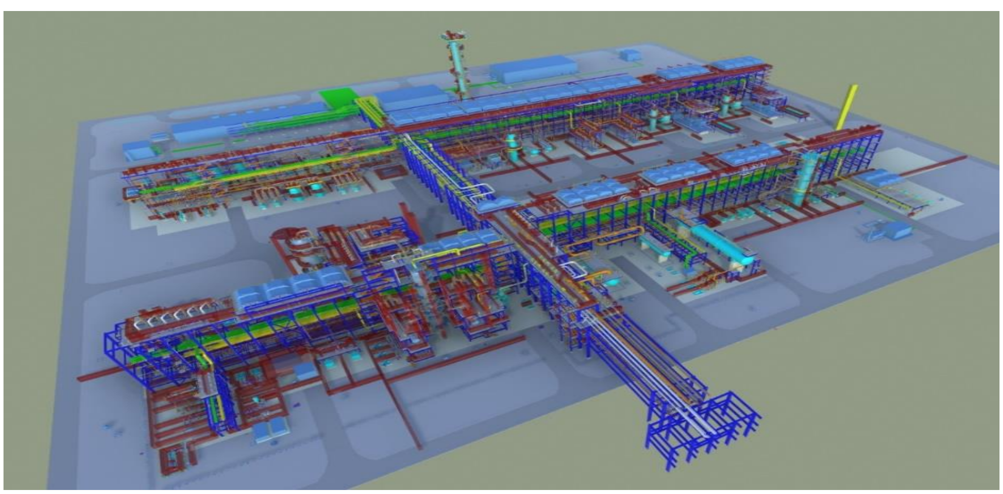

Figure 1: Project overall scope

During the design phase, the project team with their EPC contractor reviewed the construction activities schedule and it was observed that there was an impact on some of the steel structure work due to expected on-going civil activities. The idea to implement modularization method in the project was proposed as a main goal to accelerate the overall schedule. The two processing trains were divided into two sub-projects; modularization scope and traditional stick-built scope. The scope of modularization includes erecting a number of 30 Pre-assembled Racks and four pre-assembled units that will be built in an offsite location and then transported to site (Refer to Figure 2).

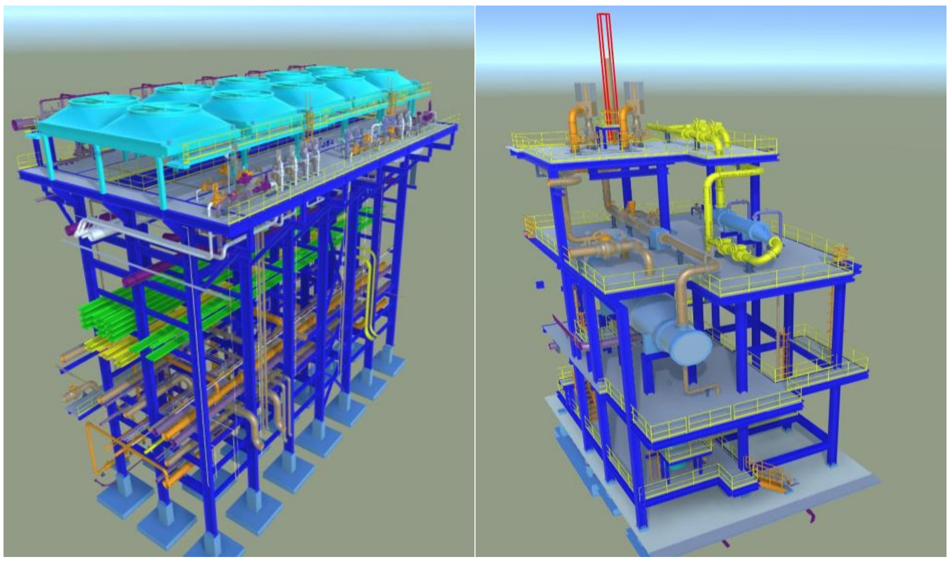

Figure 2: Piperack Model (Left); Process Units (Right)

The remaining pipe racks will be built on site using the traditional construction method (stick built). The idea started with a question of how to align between four important factors; materials storage, materials delivery dates, area of execution and transportation to site. There were three options available on the table. The first option is to fabricate the modules out of Saudi Arabia and then ship them as a complete product by sea; however, this is not feasible due to no availability of suitable port near the project location. The second option is to build it in a controlled shop in Jubail, Saudi Arabia. The distance between the fabrication shop and the project site is 350KM; however, during the logistical survey, the heights of the bridges and the underground transmission lines in addition to strict governmental regulations made this option not applicable. The third option is to choose an offsite area near the project site to build the modules and that was the option the project management team went with. They started surveying the areas in the range of the project and after careful consideration of the soil bearing capacity and other safety measures for the ground as well as the transportation route, the area was selected. The distance between the selected area (module yard) and the site is almost 3KM. As you can see in Figure 3, the transportation route was identified to coordinate with other contractors to plan ahead and have the roads ready by the time of transportation.

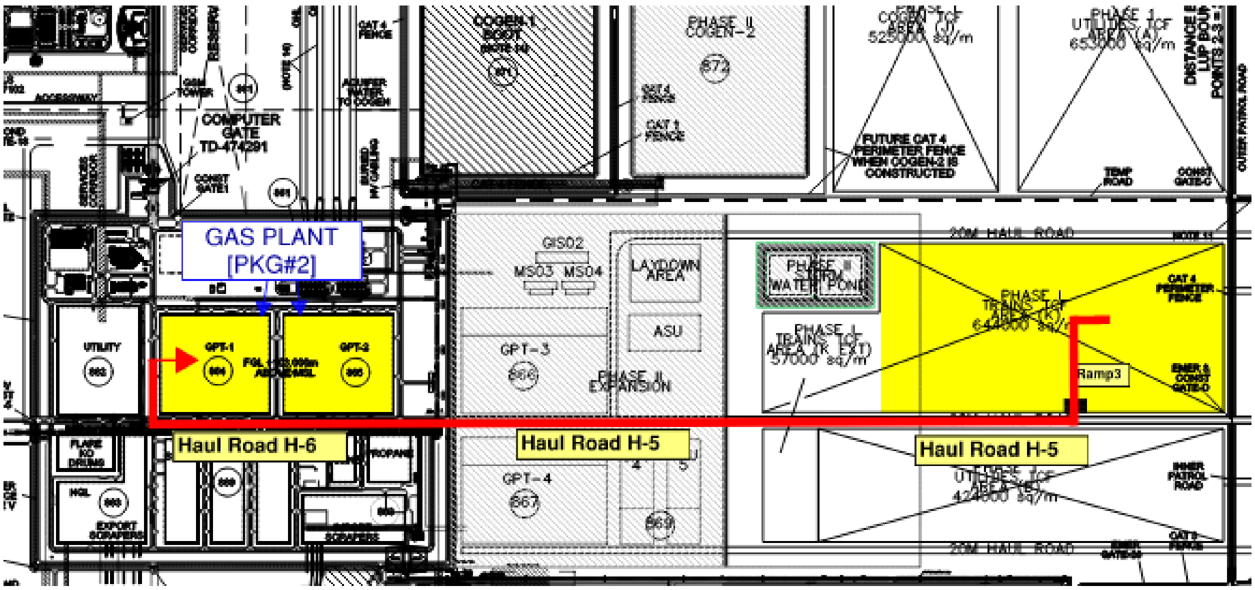

Figure 3: Transportation Route (Module Yard to Site)

Key Success Factors of Modularization in Jafurah Gas Plant

During the implementation of modular construction method, several key success factors emerge. The first success factor is the stakeholder's alignment. The idea is to involve all the stakeholders in every step along the process and to have a mutual understanding in your strategy with theirs. Detailed planning is another key factor where the planning of all site activities in a construction sequence is essential. The modularization success is all about detailed planning. If the planning is detailed and all possible scenarios have been studied, the modularization project will most likely succeed. Third success factor is the early procurement. The main point of modularization is to accelerate the overall project schedule; therefore, the materials shall be ready at site to have noticeable progress. Finally, transportation analysis is another success factor in the project. By the time of the transportation, all safety measurements shall be taken into consideration to ensure the module is safe to be transported (Figure 4). The transportation is being done by a hydraulic trailer that is specialized for modular transportation.

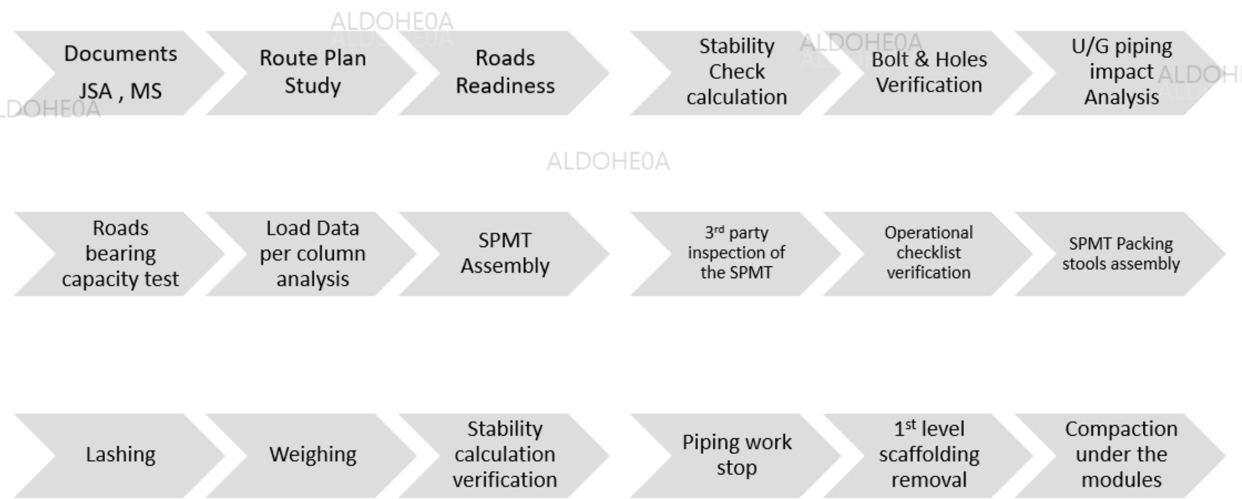

Figure 4: Transportation Requirements (Module Yard to Site)

The success itself is the implementation of the modular concept in transporting heavy modules starting from 200 tons up to 1,200 tons, which demonstrates its broad applicability in the gas industry. The key is to pay careful attention to engineering for safety, accessibility, and maintenance considerations, especially in smaller footprints, is crucial. Furthermore, addressing construction sequencing, transportation modes, design considerations, weight control, heavy haul coordination, weather windows, customs requirements, and site logistics are essential components of project success.

Challenges and Considerations in Implementing Modularization at Jafurah

As modularization gains prominence in the construction industry, it is essential to delve into the challenges and considerations associated with its implementation in Jafurah Gas Plant. The inherent complexity arises from the fact that modules often comprise various equipment, ancillary piping, control systems, and other components consolidated onto a single skid. One of the primary challenges in modularization is the intricate task of transportation logistics, particularly for large-scale modules. The transportation can become a challenge if it is not handled with close attention to all details starting from roads bearing capacity, trailer weight capacity, trailer stability, knowledge of the trailer operators, and engineering calculation for center of gravity (refer to Figure 4). Secondly, the delivery of prefabricated components from off-site fabrication facilities to the modular yard is challenging and requires close monitoring. Factors such as route selection, transportation modes, and compliance with regulations become paramount. Additionally, the consideration of underground piping during the transportation and how much the impact of the load will affect them is another challenge. Another challenge is the heat stress in the summer season, which impacts the progress of the project; however, this challenge was eliminated by switching to night shift working hours. The considerable size and weight of these modules can lead to logistical complications, escalating complexity, and driving up costs.

Standardization and Interfaces

Achieving seamless integration of modular components relies on standardization and well-defined interfaces. The lack of standardized dimensions and interfaces among modules can lead to complications during assembly. Ensuring compatibility between modules from different manufacturers becomes a crucial consideration (O'Connor et al., 2015). Addressing this challenge requires collaboration to establish common standards that facilitate interoperability, thereby streamlining the modularization process. Similarly, achieving the highest forms of quality control in the modularization process is a challenge. In most cases, project constraints can be experienced during the fabrication and the on-site assembly, which can cause huge delays (O'Connor et al., 2015). This means that project managers have to enact the highest forms of consistency to tackle compatibility during the final integration. Similarly, effective coordination between the various stakeholders is paramount and this brings together designers, fabricators, on-site construction teams, among others to reduce errors and ensure that each module fits to the overall project design.

Site-Specific Challenges and costs

The unique characteristics of construction sites in the gas processing industry bring an array of challenges. At such sites, issues such as environmental conditions, topography of the land and accessibility in most cases can affect the overall implementation of a modularization project. For example, at off-shore gas mining facilities it may be quite challenging to incorporate this strategy due to sea waves and unfavorable wealth (Cardin et al., 2015). This means that project managers have to understand the specific geographical and environmental context before undertaking any project. Similarly, although modularization has been considered for its cost saving benefits, due to reduced labor and reduced project duration, various studies argue that the upfront costs for the establishment of off-site prefabrication facilities is unattainable (Cardin et al., 2015). For the best outcomes, project managers have to carefully weigh the initial investments and long-term benefits such as time and scale of the project. All the challenges can be tackled when the project team does a thorough study of the selected site requirement and how it serves the purpose of modularization.

Human Resource and Skill Requirements

To oversee the successful implementation of a modularization project, it is integral to have skilled labor. This labor is essential both in the fabrication facilities and on site. Ensuring that workers possess the necessary expertise in precision fabrication and module assembly is essential. Human resource challenges, including the availability of skilled labor and the need for specialized training, must be addressed to guarantee the success of modular projects (O'Connor et al., 2016). To overcome this challenge, various stakeholders propose a host of strategies that are meant to tackle this challenge. Project managers can opt to re-train their employees by equipping them with the necessary skills to complete their work.

Best Industry Practices

Collaboration and Planning

Having experienced the challenges in the execution of modularization, it is important to explore what makes successful project completion in the gas mining industry. At the core of this process is early stakeholder alignment. In this case, it entails the creation of ideal working plans with the various stakeholders including designers, engineers, fabricators and on-site construction teams (Chi et al., 2015). This early collaboration helps foster shared understanding of the project goals, as well as the design requirements. This is because early communication helps streamline communication, tackle potential conflicts and create a supportive environment. Secondly, to achieve this, the strategy heavily relies on comprehensive planning and coordination (Chi et al., 2015). In this case, the planning process typically entails evaluating issues such as transport logistics, integration protocol and assembly sequence.

Design Considerations and Weight Control

Successful modularization depends on thorough design considerations that account for both individual modules and their integration into the larger structure. Designers must prioritize standardized interfaces, ensuring seamless connections between modules and compatibility with on-site components (Cardin et al., 2015). Advanced technologies like Computer aided Design (CAD) play a crucial role in optimizing the design process and facilitating coordination among multidisciplinary teams. Secondly, managing the weight of modules is a critical aspect of transportation logistics. Best practices involve optimizing module designs to meet weight restrictions, utilizing materials that balance structural integrity and weight efficiency (Cardin et al., 2015). Heavy haul coordination is equally crucial, necessitating collaboration with transportation specialists to plan routes, obtain necessary permits, and ensure the safe transport of oversized modules.

Weather Windows and Site Logistics

Considering the environmental factors of the construction site, including weather conditions, is paramount. Weather is a challenge when it comes to modules transportation. There are specific weather regulations that the transporting company require to proceed with the transportation. Identifying optimal weather windows for transportation and on-site assembly helps mitigate risks associated with adverse weather (Wildman, 2019). As an example, the gust wind speed in most cases shall not exceed 9 m/s during the transportation to avoid any risk of center of gravity displacement. Another example is during the foggy weather the operator faces difficulties with the visibility. The transporting company and the project team shall monitor the weather forecast and the actual weather condition during the transportation ensuring the full compliance with the safety regulations. Additionally, addressing site logistics involves anticipating challenges related to space, accessibility, and environmental impact, allowing for efficient module integration while minimizing disruptions. Emphasizing adherence to industry standards and certifications is a best practice that underpins the quality and safety of modularization projects (Wildman, 2019). Compliance with recognized standards ensures that modules meet specified criteria for fabrication, materials, and performance. This commitment to industry standards enhances the reliability and longevity of constructed facilities.

Project Management in Modular Constructions

Effectively managing modular construction projects demands a strategic approach that addresses the unique challenges and opportunities inherent in this construction methodology. One of the major important strategies revolves around the incorporation of an Integrated Project Delivery (IPD) (O'Connor et al., 2015). This is a collaborative approach that brings together the various key stakeholders in the project including architects, contractors and modular fabricators among others. Using the IPD helps foster open communication, which enhance the overall commitment to the project (Yin et al., 2019). This approach aligns with the key tenets of modular construction where early stakeholder involvement is paramount for supporting the decision-making process.

Digital Project Management Tools

Technology is changing the way the tenets of project management in immense ways. The incorporation of digital tools in this process is presenting project managers with new tools for communication, which is integral for effective coordination and achieving efficiency (Yin et al., 2019). Today project managers are relying on a host of tools such as cloud-based platforms such as Building Information Modeling (BIM) as well as project management software to enhance real-time collaboration between the various teams (Chi et al., 2015). By using these tools, project managers are able to share real-time information, track milestones and address any arising issues promptly. The end result of this approach is that it fosters a streamlined process that is less costly and highly effective.

Modularization-specific Project Management Training

Recognizing the unique skill set required for managing modular construction projects, investing in modularization-specific project management training is a strategic initiative. Equipping project managers with knowledge and expertise in modular construction principles, logistics, and best practices enhances their ability to navigate the intricacies of modular projects, resulting in more effective decision-making and streamlined execution (Tanabe et al., 2017). Fostering a culture of continuous improvement and incorporating feedback loops into project management processes is a forward-looking strategy. Regularly assessing project outcomes, learning from successes and challenges, and implementing feedback from stakeholders contribute to the refinement of project management strategies (Tanabe et al., 2017). This iterative approach positions organizations to adapt to evolving industry trends and enhance their modular construction capabilities.

Lessons Learned from Successful Modular Projects

Drawing insights from successful modular projects in the gas processing industry offers valuable lessons that can inform future endeavors, optimize processes, and contribute to continuous improvement. One recurring lesson from successful modular projects is the paramount importance of early collaboration and stakeholder alignment (Guccione, D., & Russell, M. 2018). Projects that involved comprehensive engagement of designers, fabricators, and on-site construction teams from the project's inception exhibited enhanced communication, shared understanding of project goals, and a collective commitment to success. Early alignment fosters a collaborative environment that is crucial for addressing challenges proactively and ensuring a cohesive vision throughout the project lifecycle.

Successful modular projects underscore the significance of meticulous planning and detailed design considerations. Projects that invested time and resources in developing comprehensive plans, including off-site fabrication, transportation logistics, and on-site assembly sequences, experienced smoother execution. Thorough design considerations that prioritize standardized interfaces and compatibility between modules further contributed to the seamless integration of modular components into the overall project (Guccione & Russell, 2018). Quality control emerged as a critical lesson from successful modular projects. Projects that implemented rigorous quality control measures at every stage, from fabrication to on-site assembly, demonstrated enhanced reliability and performance. Adhering to industry standards, conducting thorough inspections, and ensuring consistency in manufacturing standards across different modules were pivotal in preventing defects, reducing rework, and delivering high-quality outcomes. Another lesson learned is to know the weather condition you are going to face during the project execution. If the wind speed is high, the selection of equipment must accommodate the value of wind speed; otherwise, the progress will be impacted.

Effective Risk Management and Mitigation

Proactive risk management and timely mitigation strategies were evident in successful modular projects. Identifying potential risks early in the project lifecycle and implementing mitigation measures contributed to the resilience of the projects. Whether addressing transportation challenges, site-specific complexities, or design intricacies, a strategic approach to risk management minimized the impact of unforeseen challenges and ensured project timelines and budgets remained on track (Tanabe et al., 2017). Lessons from successful modular projects highlighted the importance of adapting to site-specific challenges. Recognizing the unique characteristics of construction sites, including environmental conditions, topography, and accessibility, informed effective strategies for modularization. Projects that considered site-specific challenges in their planning and execution phases demonstrated a heightened ability to navigate complexities and optimize modular construction efficiency (Tanabe et al., 2017). Effective coordination ensures that all parties were aligned with project goals, minimizing misunderstandings and accelerating issue resolution.

Conclusion and Recommendations

Modularization in gas processing facilities projects has revealed a number of challenges, and strategies that shape the landscape of construction within this dynamic sector. The study has showcased the transformative power of modularization since it enhances project efficiency and enhances precision as enshrined in the scientific management theory. By incorporating this approach, gas companies can achieve a high level of precision which is hard to attain when relying on the traditional approaches. This is because the incorporation of parallel tasks, planning and technology integration fosters collaborative and streamlined workflows which help enhance the projects. The challenges associated with modularization, such as transportation logistics, size limitations, and site-specific complexities can affect the project timelines. Understanding these challenges is paramount for organizations to develop targeted strategies for mitigation. Whether it's optimizing module designs for weight control or adapting to diverse environmental conditions, addressing these considerations is critical for the successful implementation of modular construction.

To enhance the projects, project managers need to incorporate early alignment, open communication, and shared decision-making processes to ensure that the diverse expertise involved in gas processing projects is harnessed effectively. This collaborative ethos extends from designers and fabricators to on-site construction teams, creating a unified approach that enhances project outcomes. Project-oriented organizations must prioritize strategic planning and risk mitigation when considering modular construction. The integration of advanced technologies, such as BIM and CAD, carries profound implications for project-oriented organizations. Embracing these technologies enhances collaboration, accuracy, and efficiency in the modular construction process. Project teams need to invest in training and technological infrastructure to leverage these tools effectively, ensuring a seamless digital transition in the era of modularization.

Stakeholder engagement is not only about collaboration but also about skill development. Project-oriented organizations should foster a culture of continuous learning, providing training programs that equip teams with the specialized knowledge required for modular projects. This not only enhances individual skill sets but also contributes to a more adaptable and knowledgeable workforce. In the end, and to answer the research question, the modularization method can increase the efficiency of the project in terms of cost reduction and overall project schedule optimization if the above-mentioned factors were taken into consideration. Organizations embarking on modular projects should heed the following clear conclusions and recommendations. Initiate projects with comprehensive stakeholder alignment to ensure a shared vision, enhance communication, and foster a collaborative environment conducive to modularization success. Invest in meticulous planning that considers all facets of modularization, from off-site fabrication to on-site assembly. Rigorous planning reduces uncertainties and facilitates the efficient execution of modular projects. Embrace advanced technologies like BIM and CAD to enhance precision in design and construction. The digital integration of modular components is pivotal for achieving seamless coordination and minimizing errors.

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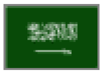

Hamad E. Aldossary holds a bachelor's degree in mechanical engineering and Master's degree in Business Administration. His master's thesis was about hygienic production technologies and the appropriate management strategy in the manufacturing industry. He has eight years of experience in project management working on projects of different sizes. He is currently a Project Engineer at Saudi Aramco to execute one of the ambitious company's mega projects (Jafurah Gas Plant). His focus as a project engineer is to implement the modularization concept successfully in the project. He is interested in developing the concept of project management to increase the efficiency of executing projects from feed phase to operations and start-up phases. He can be contacted at hamad.e.aldossary@gmail.com.