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Decision-Making Tool for Planning the Construction of Infrastructure Projects

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Abstract**—**The aim of this paper is to investigate the key drivers in planning the construction phase for infrastructure projects to reduce project delays. To achieve this aim, the research conducted three case studies using semi-structured and unstructured interviews (n = 59). The results conclude that a lack of modularization awareness is among the key factors attributed to project delays. The current emotive and ill-informed approach to decision-making, coupled with the lack of knowledge regarding appropriate construction method selection, prevents the potential benefits of modularization being fully realized. To assist with decision-making for the best construction method, the research presents project management tools to help decision makers to choose the most appropriate construction approach through optimizing the use of modularization in engineering and construction (EC). A decision-making checklist is presented in this paper. This checklist tool assists the project team in determining the best construction method, taking into consideration the module type.

Keywords**—**Infrastructure, modularization, decision support, planning.

I. Introduction

IN the last decade, Oil and Gas (O&G) and power plant projects in the Middle East have suffered significant delays. Studies by [1] and [2] revealed that these projects experience delays ranging from 5% to 20% of the total project duration. The decline in oil prices has further impacted several companies, and the sector has been pressured to reduce both project delivery time and overall cost [3], [4]. Nevertheless, the market expects oil companies to grow or at least maintain production levels, regardless of oil price. New projects need to continue to be built. As a result, projects need to be able to meet their budget and schedule targets – budgets, which will likely be significantly lower than prior to the oil price crash [1], [2], [5].

Lack of awareness of the best construction method is one of the factors commonly attributed to project cost and time overrun [6], [7]. Modern decision support strategies that are able to help decision makers to decide the best construction method in the infrastructure sector, are limited [8], [9], and even less regarding the decision-making strategies employed to help decide the appropriate construction method within each of the differing sub-sectors in infrastructure.

Given the evolving complexity of infrastructure projects, there is a clear need for up-to-date decision support tools [9]. These tools should be capable of addressing the increasingly intricate challenges faced by stakeholders in planning and executing projects effectively. This paper aims to fill this gap by investigating a decision-making tool specifically tailored for planning the best construction methods and determining the optimal split of work between offsite and onsite execution in infrastructure projects. Such a tool would be invaluable in navigating the complexities inherent in modern construction projects, including considerations such as cost, time, quality, resource allocation, and risk management. By developing a comprehensive decision support tool, this research seeks to empower project managers, engineers, and other stakeholders with the means to make informed decisions that maximize efficiency and minimize risks. The tool should be adaptable to various project contexts and capable of integrating relevant factors such as project scope, constraints, stakeholder preferences, and industry best practices.

A. Traditional Method vs. Modularization

"In recent years, construction technology has evolved from conventional site-based methods to a greater use of off-site production technologies, industrialized techniques and systematic building philosophy" [10]. Accordingly, the industry has been introduced to terms such as "offsite production, modern methods of construction, and prefabrication, pre-assembly, modularization, and off-site fabrication (PPMOF) known as prework" [10].

The focus on module classification and types within the O&G industry is crucial, especially considering the limited existing research in this area. Modularization plays a significant role in enhancing efficiency, reducing costs, and improving project delivery in complex industries like O&G [11], [13]. Therefore, further investigation into the specific types of modules used in O&G projects, such as pipe racks and piping, vendor package units, jackets decks, and precast structures, is required.

Understanding the characteristics, advantages, and challenges associated with each type of module can provide valuable insights for project planning, design, and execution [14], [15]. By examining the application of modularization across these specific types, researchers can identify best practices, potential areas for improvement, and opportunities for innovation within the O&G sector. This paper's focus on exploring these types of modules used in O&G projects, shedding light on the application of modularization within specific contexts, this paper seeks to provide valuable guidance and insights for industry professionals.

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B. Critical Success Factors for Choosing a Construction Method

Critical Success Factors (CSFs) are defined as the reasons for success and set out what action's companies need to implement to be successful [16]. CSFs include factors, methods and conditions which need to be considered by the project team throughout the project life cycle that lead to the required outcomes and which help achieve the project goals [16]. Reference [16] suggests that CSFs impact the degree of modularization in construction projects and "provide guidelines and ways to implement strategies for successful modularization in a project". Hence, CSFs help the project team to determine the best degree of modularity, through a number of actions which need to be implemented throughout the project lifecycle. This section outlines the CSFs that project teams can leverage to develop strategies for successful implementation of construction technology in infrastructure projects.

Modules sizes: There is a strong link between the module size and the shipping cost. Consideration of shipping methods and site assembly costs, access to site locations, marine or land, access to waterways and rails are among the critical factors in determining module sizes [17].

The choice of contracting strategy for module fabrication hinges on several factors, including the fabricator's location (potentially in a low-cost country), the option of engaging multiple fabricators, and the delineation of fabricators' scope—whether limited to supplying materials or encompassing fabrication as well. While utilizing multiple fabricators may expedite fabrication, it often escalates transportation costs. Therefore, the optimal decision typically involves fully fabricating the module in a factory setting. However, the use of multiple fabricators can streamline the fabrication process and reduce overall duration provided it is managed efficiently [17].

Transportation study: A study conducted by [8] emphasized the need to determine the transportation methods, the client requirement with regards to transportation, possible transportation constraints (i.e., transportation networks, road capacity), the largest possible load to be transported, and the required transportation permits as a factor to determine the suitable construction method.

Coordination between different disciplines: Project stakeholders should exploit data to support modularization optimization studies, which address all aspects of modularization cost and schedule savings, and take a different approach to scoping and configuring equipment to make it more modularization-friendly. This could only be achieved through collaboration between all project disciplines [8]. Technology and software also play a crucial role in coordination between different project disciplines. For example, consider software such as building information modelling (BIM), which enables proper tracking of materials to ensure the material is ordered on time and delivered to the right place at the right time [11].

Engineering freeze: A study conducted by [18] emphasizes the importance of establishing a design freeze early in the process. This ensures that the design remains stable and allows for effective modularization. Clients need to understand the benefits of modular design. This understanding helps them appreciate the advantages and supports successful implementation. Reference [19] stresses the need to control engineering variants to minimize interdependencies between modular components. This enhances the modularity and flexibility of the design. According to reference [12], piping and instrumentation diagram (P&ID) finalization often lags; therefore, steps must be taken to move this part of the process forward expeditiously. A late hazardous operations (HAZOP) assessment can have a severe effect on design, hence such reviews must be taken in a timely manner [17]. Consequently, the fabricator completes the production design based on final P&IDs and specifications.

II. Research Methodology

To achieve the aim and objectives, the study was divided into five stages (Fig. 1), each with its specific method of data collection, data analysis techniques, and expected outcomes.

A. Literature Review

An intensive literature review of national and international journal papers, books, reports, theses sourced from Loughborough University library, ASCE journals and ScienceDirect aimed to critically review and investigate the modularization concept, drivers and benefits in engineering and construction (EC) projects, to review the opportunities to maximize the benefits of modularization, as well as previously published decision support tools. The outcomes of this stage facilitated the identification of the literature gaps, and generated the research question, aim and objectives, and the preliminary research methodology with interview questions for data collection.

The literature revealed a small number of studies investigating the decision for modularization in the EC sector, but no research studies investigating the degree of modularization in the EC sector in the Middle East.

B. Case Studies

The primary data collection for this study was conducted through (N = 3) case studies. The data collected include the case study documents and interviews with the case participants. The case study documents include the projects' scope of work, weekly and monthly progress reports, technical reports (i.e. specifications) and project Civil and EI (Electrical and Instrumentation) drawings. (N = 59) Semi-structured and unstructured interviews were conducted online with (N = 14) participants. The interview questions were generated based on the case documents and the findings from the literature. The interviews were designed to investigate the decision-making process for the construction method (offsite/onsite) for different module type.

1. Case Study 1 Description

CS1OG includes the construction of a jetty that comprised a 3.4 km trestle, two berths, nine berthing dolphins and 14 mooring dolphins. The jetty included three buildings; each was two stories high (including the control room, substation 7A, and FF control room) and was constructed of structural steel elements. The jetty trestle was a pile structure with pile caps supporting steel modules that each spanned 40 m. The trestle accommodated a total of 19 pipelines for both process and utility lines, as well as instrumentation and power cable trays.

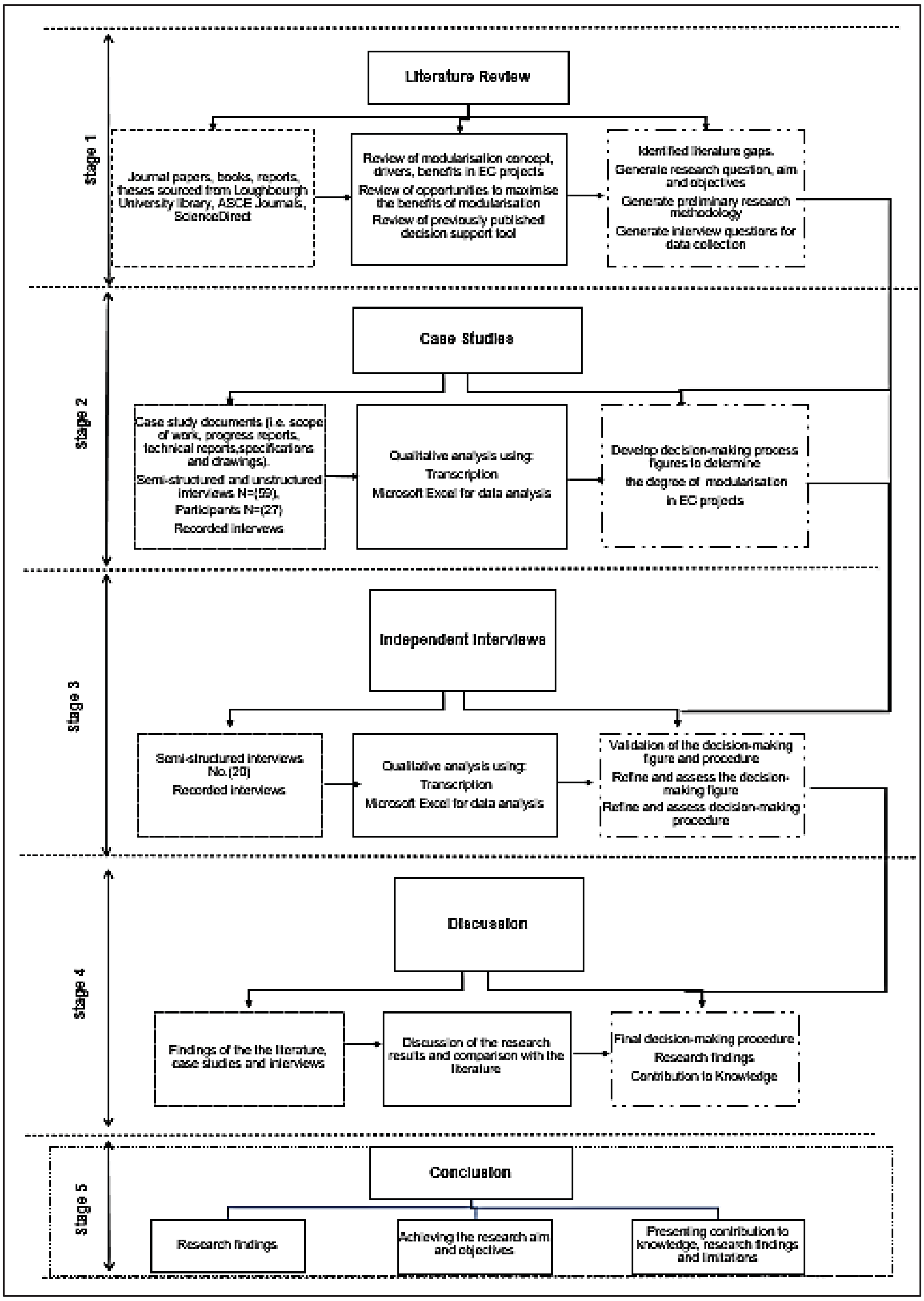

Fig. 1 Research methodology process framework

The jetty berths and platforms were composed of steel jacket structures, connected by steel trestle modules. The jackets comprise 38 piles, approximately 20 m length. The steel trestle, with a width of 15 m and height of 3 m, was constructed according to Steel Structure BS EN 10025.

Fig. 2 Case study 1 - Jacket module

Fig. 3 Case study 1- Trestle module

2. Case Study 2 Description

CS2OG is the construction of a jetty with a platform structure having five mooring dolphins and four breasting dolphins. The platform and dolphins are reinforced concrete (RC) structures supported on steel piles fitted with an appropriate fender system, in addition to all the necessary operational equipment on the top side (e.g., loading arms, gangway tower, process pipelines and equipment, utility pipelines and equipment).

Fig. 4 Case study 2: Superstructure girder assembly in project yard

3. Case Study 3 Description

CS3OG is the construction of a jetty having a platform structure with five mooring dolphins and four breasting dolphins. The platform and dolphins were RC structures supported on steel piles fitted with all the appropriate fender system. In addition to all top sides, such as loading arms, gangway tower, process pipelines and equipment, utilities pipelines and equipment, electrical and instrumentation equipment have been erected and tested.

Fig. 5 CS3OG project view

C. Module Type under Study

Fig. 6 presents the type of module under study for this paper.

1	Trestle pile
2	Trestle pile cap
3	Trestle superstructure
4	Loading platform
5	Mooring dolphin jacket
6	Mooring dolphin superstructure
7	Breasting dolphin structure
8	Breasting dolphin jacket
9	Loading platform structure

Fig. 6 Module type under study

D. Summary of Construction Method Applied

Having more than a single observer increases the reliability of evidence and increases confidence in the findings. It is important to seek out all the people who were involved in the decision-making process and are best informed about data being researched [3]. This paper investigates the key drivers in planning the construction for infrastructure projects to reduce project delay; thus, the project management teams, presented in Fig. 8 are the best participants who can provide clear and good quality data. An invitation for interviews was sent to project directors, project managers, technical office managers, and construction managers. Also, invitations for interviews were sent to engineers who worked on the case projects in the technical office and project site, as well as those who monitored the work in the fabrication yard. Fig. 8 provides a summary of the interviewees' experience for the three case studies and the main research topics that they contribute to the research.

	Modularity Degree	CS1OG	CS2OG	CS3OG
	Pipe rack and piping			
Pipe Rack	The assembly of the module in a 3D dimension module in a factory. The corrosion protection, electrical (E) and instrumentation (I) installation activities are executed offshore after all the modules are installed.	√	x	NA
Pipe Rack	The pre-assembly in a 2D dimension module is completed in a factory. The module is fabricated in 3D dimension in site yard. The corrosion protection, electrical (E) and instrumentation (I) installation activities are executed offshore after all the modules are installed.	x	√	NA
Pipe Rack	MD0:The module is fabricated in 3D dimension in the project laydown area. The corrosion protection, electrical (E) and instrumentation (I) installation activities are executed offshore after all the modules installed at their final location	x	x	NA
Pipe Rack	MD3: The assembly of the module in 3D dimension and electrical (E) and instrumentation (I) installation are executed in the factory	x	x	NA
Piping	The assembly of the module in a 3D dimension module in a factory. The corrosion protection, electrical (E) and instrumentation (I) installation activities are executed offshore after all the modules are installed.	√	NA	x
Piping	The pre-assembly in a 2D dimension module is completed in a factory. The module is fabricated in 3D dimension in site yard. The corrosion protection, electrical (E) and instrumentation (I) installation activities are executed offshore after all the modules are installed.	x	NA	x
Piping	The module is fabricated in 3D dimension in the project laydown area. The corrosion protection, electrical (E) and instrumentation (I) installation activities are executed offshore after all the modules installed at their final location	x	NA	√
	Substructure			
Jackets	The assembly of the module in a 3D dimension module in a factory. The corrosion protection, electrical (E) and instrumentation (I) installation activities are executed offshore after all the modules are installed.	√	NA	√
Jackets	The pre-assembly in a 2D dimension module is completed in a factory. The module is fabricated in 3D dimension in site yard. The corrosion protection, electrical (E) and instrumentation (I) installation activities are executed offshore after all the modules are installed.	x	NA	x
Jackets	The module is fabricated in 3D dimension in the project laydown area. The corrosion protection, electrical (E) and instrumentation (I) installation activities are executed offshore after all the modules installed at their final location	x	NA	x
Jackets	Fabricate the system (steel and EI) in factory, transport to site and install in place	x	NA	x
Piles	The assembly of the module in a 3D dimension module in a factory. The corrosion protection, electrical (E) and instrumentation (I) installation activities are executed offshore after all the modules are installed.	x	x	√
Piles	The pre-assembly in a 2D dimension module is completed in a factory. The module is fabricated in 3D dimension in site yard. The corrosion protection, electrical (E) and instrumentation (I) installation activities are executed offshore after all the modules are installed.	x	x	x
Piles	The module is fabricated in 3D dimension in the project laydown area. The corrosion protection, electrical (E) and instrumentation (I) installation activities are executed offshore after all the modules installed at their final location	√	√	x
Piles	Fabricate the system (steel and EI) in factory, transport to site and install in place	x	x	x

Fig. 7 The utilization of different modularization elements

Case Study	*Years of experience*	*No.*	*Decision-making Process*	*Drivers*	*Challenges*	*Reasons for selected methods*	*Technical information*	*Lessons learned in fabrication and transport*
CS1OG	>30	1	√	√	√	√	√	√
	20-30	1	√	√	√	√	√	√
	10-20	4	x	√	√	x	√	√
CS2OG	>30	1	√	√	√	√	√	√
	20-30	1	√	√	√	√	√	√
	10-20	2	x	√	√	x	√	√
CS3OG	>30	1	√	√	√	√	√	√
	20-30	1	√	√	√	√	√	√
	10-20	2	x	√	√	x	√	√

Fig. 8 Case study participant's profile and interview topics

III. Results and Contribution

A. Drivers for the Decision of the Construction Method

The analysis of this paper introducing additional drivers for decision-making about construction method in Fig. 9, which has not been examined in previous studies. These key drivers obtained during the data collection and literature review stages in the column titled 'Drivers'.

Design	Module material type is not standard, needs computer-based equipment NOT available in the contractor yard and available in the fabricator yard
Design	The full length of the module cannot be transported on a standard trailer Needs additional logistical requirements, resulting in extra cost and time Marine transportation is not an option or is more expensive and time consuming The weight and dimensions of the module could be fabricated or pre-assembled on site
Design	The weight and dimensions of the module could be fabricated or pre-assembled on site
Site Constraints	The project location does not have a sea front. Thus, equipment (module) cannot be transported to the site location by sea. The whole module cannot be transported to the site from the harbour by land.
Site Constraints	No available space in the project laydown area to set up a workshop
Process	The fabricator does not have enough laydown area to fabricate and store the module under study
Process	The material is free-issued by the client and shipped to the site. Avoids mix of material and facilitates identification of the different materials (carbon steel, stainless steel, LTCS), sizes and types
Transportation	Size and weight of the module is manageable to be transported by land or marine
Transportation	The module as a complete unit is not possible to be transported by land or marine due to its size and weight
Transportation	Size and weight of the module need infrastructure modifications which incur extra time and cost
Transportation	Marine transportation is cheaper than land and the shipments could include several modules per trip
Transportation	The contractor must use sea transportation, which is much higher in cost than land transportation
Transportation	If land transportation is an option, the module structure needs to be divided into parts to fit the width of a standard trailer, which might increase the number of site welds
Transportation	Land transportation: modules need to be divided into parts to fit the width of the standard trailer; this is the only transportation method to transport modules to the project location
Transportation	i- distance between the fabricator and project location is too far. If land transportation is used to transport the full module size, the duration of the trip might not fit the overall project schedule
Transportation	The number of modules to be delivered as one unit per trip, using land transportation, is not cost efficient and could delay the overall project The material is free-issued to the main contractor; additional costs need to be considered to deliver the material to the fabricator

Fig. 9 Drivers affect the decision for suitable construction method

B. Decision-Making Support Tool for Construction Method

Decision-making tool has been developed in this study to determine the possible modularity degree options for every module type. The checklist presents all the drivers affecting decision-making for modularization, a total number of 10 Key drivers have been identified as an outcome of the analysis of the primary data in addition to what was previously published. These key drivers include Design, Site constraints, Process, Resources, Transportation, Quality and administration.

		Structure Modularisation MD2S					Component Modularisation MD1S					Traditional MD0S				
key Drivers	Description	Jacket	Piles	Pile C	Trestle	LP, BI	Jacket	Piles	Steel	Trestle	LP, BI	Jacket	Piles	Pile C	Trestle	LP, BI
Design	Module material type is not standard, needs computer-based equipment NOT available in contractor yard but available in fabricator yard	√	NA	NA	√	√	X	X	X	X	X	X	X	X	X	X
Site Constraint	The project is located in remote regions, skilled labour is not available in the project area to consider prefabricating module in project yard	X	X	X	X	X	X	√	√	√	X	X	√	√	√	X
Process	There are specialised fabricators worldwide with experience in similar jobs, who can provide the contractor with the required number of modules in a	X	X	X	X	X	NA	√	√	√	X	NA	X	X	X	X
Resources	Purchase equipment is required for the site workshop, which will be idle after the project	√	√	√	√	√	√	√	√	√	√	X	X	X	X	X
Transportation	Size and weight of module is manageble to be transported by land or marine	√	√	√	√	√	X	√	√	√	√	X	X	X	X	X
Quality	The quality in the factory is higher than on site	√	√	√	√	√	X	√	√	√	√	X	X	X	X	X
Adminstaratio	The ease of issuing permits and the logistics to deliver the module to site	√	√	√	√	√	X	√	√	√	√	X	X	X	X	X

Fig. 10 Decision-making tool template

The main drivers influencing the decision for selecting a construction method are illustrated in Fig. 10, which outlines the key drivers and provides a detailed description of each. The figure categorizes all possible construction methods based on the type of module considered, organizing them into four distinct categories: MD1, MD2, MD3, and MD4.

- MD1S: The module is fabricated in 3D in the site yard. The corrosion protection, electrical (E) and instrumentation (I) installation activities are executed offshore after all the modules are installed.
- MD2S: The pre-assembly in a 2D module is completed in a factory. The module is fabricated in 3D in the site yard. The corrosion protection, electrical (E) and instrumentation (I) installation activities are executed offshore after all the modules are installed.
- MD3: The assembly of the module in 3D dimension and electrical (E) and instrumentation (I) installation are executed in the factory.
- MD0C Traditional concrete - In situ concrete.
- MD1C: The concrete module is precast in the project yard, lifted and installed in place.

C. Tool Explanation and Purpose

The decision-making tool described in Figs. 11-17 is designed to determine the possible modularity degree options (construction method) for each module type within the O&G industry. Here is how it works:

Quantifying and Comparing Main Drivers: The tool quantifies and compares the number of main drivers (e.g., design, transportation) for each modularity degree option corresponding to every driver. For example, if a modularity degree option aligns with multiple main drivers, it would receive a higher score. This process helps in evaluating the suitability of each modularity degree option based on its alignment with project requirements and constraints.

Listing All Drivers Affecting Decision-Making: The tool lists all the drivers that affect decision-making for the construction method, including aspects such as design requirements, transportation considerations, cost factors, and project constraints.

Users to Inserting Legend Corresponding to Drivers: Users of the tool insert a legend (symbolized by √) corresponding to the drivers that are relevant to their project circumstances. For instance, if transportation constraints are significant for a particular project, the user would mark the transportation driver (√) in the tool.

Calculating Sub-total and Total Key Drivers: The tool then calculates and provides sub-total and total numbers of key drivers supporting each modularity option. This calculation considers the number of main drivers aligned with each modularity degree option, providing a quantitative assessment of the suitability of each option.

Providing a Summary of Tool Results: In the final stage, the tool generates a summary of outcomes for all module types. This summary consolidates the results obtained for each module type, highlighting the recommended modularity degree options based on the alignment with key project drivers.

Overall, the decision-making tool provides a quantitative assessment of the suitability of modularity degree options for different module types, helping stakeholders make informed decisions based on the alignment with key project drivers and constraints.

1. Design Driver

The tool presented all the drivers that influence the decision for best construction method, based on the research analysis and literature review. Design drivers (Fig. 11) encompass factors such as the length of the module to be transported and its compatibility with a standard trailer, as well as required additional logistics such as permits and construction of infrastructure, which can result in additional costs and time. The module material type, whether standard or requiring computer-mode equipment, if not available in the contractor's yard, is accessible in the fabricator's yard.

	Structure Modularisation MD2S					Component Modularisation MD1S					Traditional MD0S				
Description	**Jackets**	**Piles**	**Pile Cap**	**Trestle (Pipe Rack)**	**LP, BD, MD Deck**	**Jackets**	**Piles**	**Steel Pile Cap**	**Trestle (Pipe Rack)**	**LP, BD, MD Deck**	**Jackets**	**Piles**	**Pile Cap**	**Trestle (Pipe Rack)**	**LP, BD, MD Deck**
Module material type is not standard, needs computer-based equipment NOT available in contractor yard but available in fabricator yard	√	NA	NA	√	√	X	X	X	X	X	X	X	X	X	X
Full length of the module cannot be transported in a standard trailer. Needs additional logistical requirements, resulting in extra cost and time. Marine transportation is not an option	X	X	X	X	X	X	√	√	√	X	X	√	√	√	X
The weight and dimension of the module is manageable to be fabricated, or preassembly on site	X	X	X	X	X	NA	√	√	√	X	NA	X	X	X	X
Types and sizes of modules considered. Since a huge trade-off exists between module size and shipping costs, considerable thought must be given to module size and configuration.	√	√	√	√	√	√	√	√	√	√	X	X	X	X	X
Use of repetitive components in design	√	√	√	√	√	X	√	√	√	√	X	X	X	X	X
The design is suitable for modularisation	√	√	√	√	√	X	√	√	√	√	X	X	X	X	X
Total number of design drivers to support decision-making for the modularity degree	4	3	3	4	4	1	5	5	5	3	0	1	1	1	0

Fig. 11 Decision-making tool- Design driver

Following the tool, four design drivers to support decisions for MD2 for jacket structure, marked as (√) in the column titled 'Structure modularization/Jackets' (Fig. 11). One main driver to support the decision for MD1, marked (√) in the column titled 'Component modularization/Jackets', and one main driver to support the decision for MD0. The suitable modularity degree for jackets is MD2.

2. Site Constraints

The findings of this research suggest that various factors such as the cost of local labour, availability of skilled labour in the project area, and space in the project laydown area, exists as constraints for setting up a workshop. Restrictions in the use of land and the construction method used contribute to lower mobilization cost. These additional drivers are incorporated into the tool as Fig. 12.

	Structure Modularisation MD2S					Component Modularisation MD1S					Traditional MD0S				
The project is located in remote regions, skilled labour is not available in the project area to consider prefabricating module in project yard	√	√	√	√	√	x	x	x	x	x	x	x	x	x	x
The project location does not have a sea front. Thus equipment (module) cannot be transported to the site location by sea. The whole module cannot be transported to site from the harbour by land.	x	x	x	x	x	x	√	√	x	√	x	√	√	√	x
No available space in project laydown area to set up a workshop (go for full)	√	√	√	√	√	x	x	x	x	x	x	x	x	x	x
Setting up a workshop in site w	√	√	√	√	√	x	x	x	x	x	x	x	x	x	x
Contractor has a sufficient fabri	x	x	x	x	x	x	x	x	√	√	x	√	√	√	x
Project location is suitable and cost competitive resources are available	x	x	x	x	x	√	√	√	√	√	x	√	√	√	x
The construction method results in lesser mobilisation of resources (manpower + equipment), Lesser set up of	√	√	√	√	√	x	√	√	√	√	x	x	x	x	x
Site preparation is very significant	√	√	√	√	√	x	x	x	x	x	x	x	x	x	x
Climatic conditions are challenging	√	√	√	√	√	x	√	√	√	√	x	x	x	x	x
Restrictions on use and avaialability of land	√	√	√	√	√	x	√	√	√	√	x	x	x	x	x
Remote areas with difficult access	√	√	√	√	√	x	√	√	√	√	x	x	x	x	x
Total number of Site constraints drivers to support the decision-making for the modularity degree	**8**	**8**	**8**	**8**	**8**	**1**	**6**	**6**	**6**	**7**	**0**	**3**	**3**	**3**	**0**

Fig. 12 Decision-making tool- Site constraints driver

Following the decision-making tool for jacket fabrication, eight main site constraints drivers to support decisions for MD2 (Fig. 12), marked as (√) in the column titled 'Structure modularization/Jackets, one main driver to support the decision for MD1, marked (√) in the column titled 'Component modularization/Jackets', and zero main driver to support the decision for MD0. The suitable modularity degree for jackets is MD2.

3. Process Driver

		Structure Modularisation MD2S					Component Modularisation MD1S					Traditional MD0S				
Process	There are specialised fabricators worldwide with experience in similar jobs, who can provide the contractor with the required number of modules in a suitable delivery period that fits the overall schedule.	√	X	X	√	√	X	X	X	X	X	X	X	X	X	X
	External fabricators have previous experience in fabrication and of handling similar structures.	√	X	X	√	√	X	X	X	X	X	X	X	X	X	X
	Fabricators have good safety re	√	X	X	√	√	X	X	X	X	X	X	X	X	X	X
	Fabricators have a stable and skilled workforce in the module fabrication area	√	X	X	√	√	X	X	X	X	X	X	X	X	X	X
	Fabricator is a subsidary company of the main company	√	√	√	√	√	√	√	√	√	√	√	X	X	X	X
	The main contractor has experience in similar type of works	√	√	√	√	√	√	√	√	√	√	X	X	X	X	X
	Fabricator has a seafront yard a	√	X	X	√	√	√	√	√	√	√	X	X	X	X	X
	Fabricator has sufficient fabrication capacity that fulfills the schedule requirements	√	√	√	√	√	√	√	√	√	√	X	X	X	X	X
	Fabricator does not have enough laydown area to fabricate and store the module under study	X	X	X	X	X	X	√	√	√	√	X	√	√	√	√
	Fabricator is not in or near the project area, the client requires full quality control and supervises the module	X	X	X	X	X	X	√	√	√	√	X	√	√	√	√
	The material is free-issued by the client and shipped to the site. Avoids mix of materials and facilitates the identification of the different materials (carbon steel, stainless steel, LTCS), sizes and types	X	X	X	X	X	X	√	√	√	√	X	√	√	√	√
	Fabricator has good quality rec	√	X	X	√	√	√	√	√	√	√	X	X	X	X	X
	Total number of drivers to support decision-making for the correct degree	**9**	**3**	**3**	**9**	**9**	**5**	**8**	**8**	**8**	**8**	**1**	**3**	**3**	**3**	**3**

Fig. 13 Decision-making tool- Process driver

4. Resources Drivers

Based on the results analysis, one of the main considerations for modularization is the issue of resources, which has been added to the decision-making tool. Labour requirements, the lack of available labour at the project site or in the local area, any restrictions on site labour due to access and/or available land, or the relative labour rates and productivity levels for the site and potential module yards.

		Structure Modularisation MD2S					Component Modularisation MD1S					Traditional MD0S				
Resources	Purchase equipment is required for the site workshop, which will be idle after the project	√	√	√	√	√	X	X	X	X	X	x	x	x	x	x
	Contractor has the required equipment and labour	x	√	√	√	x	X	X	X	X	X	x	√	√	x	x
	Local labour costs are high in the project area	√	√	√	√	√	X	X	X	X	X	x	x	x	x	x
	Limited availability of labour in the project area	√	√	√	√	√	X	X	X	X	X	x	x	x	x	x
	Total number of drivers to support decision-making for the correct degree	**3**	**4**	**4**	**4**	**3**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**0**

Fig. 14 Decision-making tool- Process driver

5. Transportation Drivers

Transporting modules across the country requires experienced shipping and traffic coordinators. Even though some shipping restrictions are straightforward, many municipalities, counties, and townships, for projects where significant land transportation of the modules is required, the module size will be limited by any road and carrier restrictions.

		Structure Modularisation MD2S					Component Modularisation MD1S					Traditional MD0S				
Transportation	Size and weight of module is manageble to be transported by land or marine	√	√	√	√	√	√	√	√	√	X	X	X	X	X	√
	Fabrication of the module as one unit is not manageble to be transported by land or marine due to size and weight	X	X	X	X	X	√	√	√	√	X	X	√	√	X	√
	Size and weight of the module need infrastructure modifications resulting in extra time and cost	X	X	X	X	X	√	√	√	√	X	X	√	√	X	√
	Marine transportation is cheaper than land; the shipments could include a number of modules per trip	√	X	X	√	√	X	X	X	X	X	X	X	X	X	X
	Marine transportation is available and the whole module could be delivered as scheduled	√	√	√	√	√	X	X	X	X	X	X	X	X	X	X
	The contractor has to use sea transportation which is much higher in cost than land transport	X	X	X	X	X	X	√	√	√	X	X	√	√	X	X
	If land transportation is an option, the module structure needs to be divided into parts to fit the width of the standard trailer, which might increase the number of site welds	√	√	√	√	√	X	X	X	X	X	X	X	X	X	X
	If land transportation is the only option to transport modules to the project location, the modules need to be divided into parts to fit the width of the standard trailer	X	X	X	X	X	√	√	√	√	√	X	X	X	X	X
	The distance between the fabricator and project location is too far. If land transporation is used to transport the full module size, the duration of the trip might not fit the overall project schedule.	X	X	X	X	X	X	X	X	√	√	X	√	√	X	X
	The number of modules to be delivered as one unit per trip using land transportation is not cost efficient and could delay the overall project	√	√	√	√	√	X	X	X	√	X	X	X	X	X	X
	The material is free-issued to the main contractor, additional costs need to be considered to deliver the material to the fabricator	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Total number of drivers to support decision-making for the correct degree	**5**	**4**	**4**	**5**	**5**	**4**	**5**	**5**	**7**	**2**	**0**	**4**	**4**	**0**	**3**

Fig. 15 Decision-making tool- Transportation driver

Following the decision-making tool, five transportation drivers to support decisions for MD2 from the transportation perspective for jacket structure (Fig. 15), marked as (√) in the column titled 'Structure modularization/Jackets. Four main drivers to support the decision for MD1, marked (√) in the column titled 'Component modularization/Jackets', and one main driver to support the decision for MD0. Accordingly, the suitable modularity degree for jackets is MD2.

6. Quality Drivers

		Structure Modularisation MD2S					Component Modularisation MD1S					Traditional MD0S				
Quality	The quality in the factory is higher than on site	√	√	√	√	√	√	√	√	√	√	x	x	x	x	x
	The contractor has to dedicate a quality team in the fabricator yard to follow the progress of work resulting in additional costs	x	x	x	x	x	NA	√	√	√	√	x	√	√	√	√
	Ensure the quality of work as per client requirements	√	√	√	√	√	√	√	√	√	√	x	√	√	√	√
	Total number of drivers to support decision-making for construction method	**2**	**2**	**2**	**2**	**2**	**2**	**3**	**3**	**3**	**3**	**0**	**2**	**2**	**2**	**2**

Fig. 16 Decision-making tool- Quality drivers

D. Outcomes of Decision-Making Support Tool for Suitable Construction Method

In the final stage, the tool generates a summary of outcomes for all module types (see Fig. 17). This summary consolidates the results obtained for each module type, highlighting the recommended modularity degree options based on the alignment with key project drivers. Based on the example provided for jackets modules (Figs. 11-16), the decision-making tool indicates that there are 31 main drivers supporting the decision for Modularity Degree 2 (MD2), marked as (√) in the column titled 'Structure Modularization/Jackets'. Additionally, there are 14 main drivers supporting the decision for Modularity Degree 1 (MD1), marked (√) in the column titled 'Component Modularization/Jackets', and one main driver supporting the decision for Modularity Degree 0 (MD0). The analysis suggests that MD2 is the suitable modularity degree for jackets modules, as it is supported by the highest number of main drivers, indicating a higher level of alignment with project requirements and constraints.

Module Description	Number of drivers to support a particular degree of modularity					
	O&G			Power plants		
	MD2 S	MD1 S	MD0 S	MD2 S	MD1 S	MD0 C
Jackets	31	13	1	0	0	0
Piles	24	27	14	21	27	17
Pile Caps	24	27	14	12	0	17
Pipe rack	32	29	9	18	28	0
Steel Superstructure	31	23	8	0	28	0

Fig. 17 Outcomes of the tool results for all module types- Jacket example

IV. Conclusions

There are very few studies providing models or processes for selecting construction systems, methods or materials for construction. Those that do exist, however, focus mainly on the presentation of weighting and scoring processes, but are not clear on establishing the decision context, justifying the criteria applied, or the options considered. Furthermore, these studies focus on building, with little published regarding in engineering, procurement and construction (EPC), more specifically O&G and the downstream sector.

Therefore, this research is concerned with examining the process of making decisions on the best construction method and modularity degree in that sector. This comparison is necessary to address a specific gap in the current body of knowledge. The research contributes to this area by presenting a decision-making tool (Figs. 11-17), which includes all the drivers and sub drivers collected in this research that are involved in the choice of a suitable modularity degree.

The decision-making tool presented helps determine the possible options of modularity degree for every module type, in order to subsequently select the correct one. This is achieved by quantifying and comparing the number of main drivers labelled (√) for each modularity degree option. By inserting the legend (√) corresponding to the appropriate drivers to project circumstances, the table calculates the sub-total and total numbers of key drivers to support each modularity option.

V. Implications

The literature review highlights a notable gap in research concerning tools for selecting the appropriate construction method in engineering, procurement and construction (EPC) projects. This research suggests that the decision-making tool could serve as valuable aids in guiding decision-making regarding modularity levels, particularly within the Oil and Gas (O&G) industry. The tool provides a structured approach to a complex decision-making process, assisting individuals in comprehending and navigating difficult problems. By leveraging these resources, stakeholders in the O&G industry can enhance their ability to make informed decisions regarding the suitable construction method or degree of modularization in their projects, potentially leading to improved efficiency and effectiveness in project outcomes.

VI. Limitations and Future Research

The data collection for this study utilized qualitative research methods to conduct a detailed examination of the drivers and barriers influencing the degree of modularization in the engineering and construction (EC) sector, specifically focusing on the downstream segment. While the study included two case studies involving independent interviews, it is worth noting that these case studies only represent the strategies of a single company. However, insights from independent interviews with representatives from seven other companies were also considered.

Furthermore, the decision-making support checklist developed in this research assigns equal weight to the drivers for modularization, potentially overlooking variations in their significance. Moving forward, it is imperative that research continues to explore the utilization of modularization technologies in industries such as O&G and power plants. This ongoing investigation can provide further insights and contribute to realizing the industry's goals of improving project delivery across dimensions of time, cost, and quality. The study offers the following recommendations for future research:

Conduct Surveys within the O&G Sector: This could provide valuable insights into the implementation of modularization strategies. Surveys can offer a broader perspective by gathering input from a larger pool of stakeholders across various organizations within the O&G industry. They can help identify common trends, challenges, and best practices associated with modularization and its integration with technology. Additionally, surveys can capture quantitative data that complements the qualitative insights gained from interviews and case studies. By systematically collecting data through surveys, researchers can enhance their understanding of the factors influencing modularization decisions, the effectiveness of different integration strategies, and the overall impact on project delivery outcomes. This deeper understanding can inform the development of more robust frameworks, guidelines, and tools for implementing modularization in the O&G sector, ultimately contributing to improved project efficiency and performance.

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