Decision Support for Modularization: Engineering Construction Case Studies

R. Monib, C. I. Goodier, A. Gibb

Abstract**—**This paper aims to investigate decision support strategies in the EC sector to determine the most appropriate degree of modularization. This is achieved through three oil and gas (O&G) and two power plant case studies via semi-structured interviews (n = 59 and n = 27, respectively), analysis of project documents, and case study-specific semi-structured validation interviews (n = 12 and n = 8). Terminology to distinguish degrees of modularization is proposed, along with a decision-making support checklist and a diagrammatic decision-making support figure. Results indicate that the EC sub-sectors were substantially more satisfied with the application of component, structural, or traditional modularization compared with system modularization for some types of modules. Key drivers for decisions on the degree of modularization vary across module types. This paper can help the EC sector determine the most suitable degree of modularization via a decision-making support strategy.

Keywords**—**Modularization, engineering construction, case study, decision support.

I. Introduction

RECNTLY, the engineering construction (EC) sector has experienced a challenge to the delivery of construction projects on budget and on schedule, whilst maintaining high quality performance. One strategy that companies are increasingly employing to help cope with these challenges is modularization [1]-[4]. Although decision making for building modularization has previously been examined [4], [5], it has rarely been investigated in the EC context, [6]-[8] and even less, the decision-making support tools used to support the client during the early stages of a project. This paper investigates the decision support strategies employed in the EC sector to determine the best degree of modularization.

Modularization is "the preconstruction of a complete system away from the job site that is then transported to the site" [4]. Modularity is defined by [9], however, as a "strategy for organizing products and process efficiently". According to [10], there are three types of modularity: i) product design modularity; ii) process modularity; and iii) organizational modularity. Process modularity includes groups that have weak connections, to enable the sequence of the process to be changed due to the independency of each process module [10]. The *process* module can be disconnected easily in case of a change in the *product* module [11]. Product modularity is "A method of designing a product based on well-defined interfaces and architecture that improves the design and the process operations more efficiently by decomposing complex systems into subsystems" [12]. Organizational modularity refers to the percentage or amount of work that could be disconnected and then recombined to work efficiently [13].

A. Degree and Measures of Modularity

The degree of modularization is defined by [4] as the percentage and/or the amount of offsite preassembly in a construction project. The number of structures modularized in a construction project compared to the traditional construction approach has also been used as a measure [4].

According to [14] and [15], literature lacks agreed measures for the degree of modularity. According to [16], the complexity of the production process is connected to the degree of modularity of a product. Reference [17] noted the "Singular Value Modularity Index" (SMI) could be used to determine the degree of modularity of a product [5]. SMI ranges between 0-1; SMI nearer to 1 refers to a higher degree of modularity. Reference [18] suggests that the literature lacks a "clear measure of product modularity" and a clear approach to support designers to increase the degree of modularity, as agreed by [19]. A method to measure the degree of modularity addressing the relationship between product modularity and how modular components and interfaces are factors in the degree of modularity [20]. The study [20] further emphasizes key elements of modularization (including modular component, standardization and degree of coupling), and then proposes a model to measure the impacts of these measures on the degree of modularity.

Reference [4] measures the degree of modularity through developing a model decision flow chart to support in determining the best degree of modularity, by optimizing the design of the module. The decision chart evaluates different modular approaches, through cost/benefits (cost of work hours in on-site vs fabrication yards) [4].

B. Modularization Drivers

Modularization drivers and benefits are 'closely related' and play a crucial role in decisions in favour of modularization [21]. Drivers are motivations for the decision to implement or otherwise modularization in a project [17].

Numerous studies have suggested modularization could improve productivity during the construction phase [22]-[27]. Reference [28] revealed that cost, time and quality are the main criteria in deciding on modularization. In addition, the study

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emphasized that environmental issues are among the main drivers [28]. Thus, modularization is considered a good solution to increase site productivity in countries that have unstable weather conditions. Conversely, [5], [29]-[31] offer a different opinion, and prioritizes the period of projects over any other factors, suggesting that projects restricted by schedule (e.g., schools), having repetitious elements or special requirements better suit modular design. For EC, drivers for modularization often vary with the type of module under study [5], [30], [32].

Cost: There is debate whether cost acts as a driver to reduce project cost through modularization e.g. [21], [33]-[35], via reducing costs associated with site infrastructure and overheads. Fewer workers on site means less costs for accommodation, fewer material deliveries and less crane usage. The cost of transporting large, pre-assembled units may provide savings over many shipments of individual pieces, including storage costs [14], [21], [29].

To improve and shorten the overall project schedule is a key factor in the decision for modularization technology in the EC sector. Moving part of the scope of work to a factory, while other activities are in progress in parallel at the project site, usually reduces the conflict between crews and the interference with ongoing activities, and the overall schedule [4], [22], [30]-[32].

Quality: Modular structures are usually tested and certified before delivery to site, with reliability more predictable in the factory, thus the possibility of an error or delay is reduced. It enhances the quality and reduces the inspection and test costs [5], [21], [30], [34].

Labour availability and site location: Projects located in remote regions with limited site access and severe weather conditions can experience labour unavailability problems. Modularization can reduce the skilled labour required on site, and associated costs resulting from relocation and accommodation. Work can be fabricated and assembled in areas where labour is available, and the modules then shipped to site [21], [25], [34].

Safety: Studies agree that factory fabrication is safer than on-site, with less fall-related (and other types of) injuries [21], [30], [34].

However, there is no clear evidence to suggest that the drivers for decisions on the *use* of modularization are the same that are used to decide on the different *degrees* of modularization or generation. Furthermore, the literature presented mainly investigates the construction/building industry, with no clear evidence that drivers for modularization decisions are the same across different sectors and construction projects. MODEX software claims to provide the user with three levels of feasibility analysis: pre-screening, detailed feasibility, and economic analysis. The pre-screening process, factors to be assessed are those related to project location, labour considerations, environmental and organizational issues, plant characteristics and project risks, and project location [34], [35].

C. Decision Making for Modularization

In the late 1980s, Construction Industry Institute (CII) developed a modularization decision-making software tool called MODEX, to enable the project team to assess the feasibility of using modularization for industrial [36].

If the project is found to have a certain potential for modularization of more than 25%, the project moves to the next evaluation stage, which is a detailed feasibility and economic assessment. If the potential for modularization is less than 25%, then it is suggested that the project should use the conventional non-modular method of construction [36].

In the second stage, a detailed feasibility study is conducted to determine which design and construction methods are more useful for a particular project. In the third stage MODEX provides the user with an economic analysis through providing an indicative trend for cost savings or increases [34]. CII also produce other software in addition to MODEX called the Multimedia Decision Support System (MDSS) [21]. The system combined project data with MODEX and consists of four modules. The first module includes criteria for decision-making and weight factors. The second module contains all data related to the project under study. The third module contains a graphical database (i.e., site conditions and transportation) related to the project in question. The fourth module takes the three modules into consideration and uses a group decision-making algorithm to help determine a solution [21]. MODEX tool has been developed to assist in deciding the feasibility of modularization vs traditional method for industrial construction projects. However, this research is concerned with investigating the decision-making support for the degree of modularity.

Previous studies developed a decision-making process and framework to assist in decision-making for product modularization alternatives during the conceptual design phase [37]-[40]. However, decision-making process and framework have been assessed in one industrial case study. Hence, further investigation is still required. Construction companies however, still use decision-making support checklists to decide on the degree of modularization, with the majority considering only the impact of site constraints on the decision for the degree of modularity [40]. This paper investigates the decision-support procedure and checklist considering all drivers affecting the different degrees of modularization.

III. Research Methodology

A. Case Studies

Case study data can be obtained from several sources such as documents, archival records, interviews, direct and/or participant observation. Three case studies examined the decision-making support for modularization in midstream oil and gas (O&G) sector projects (CS1OG, CS2OG and CS3OG) and two cases in power plant projects (CS4PP and CS5PP). Data were obtained using diverse sources such as drawings, archival records of meetings, method statements, the scope of work and specifications (Fig. 1).

CS1OG, CS2OG and CS30G had an illustrative and descriptive purpose: to investigate the company's procedures and systems to decide the modularity level to achieve higher productivity, keep the project on schedule and avoid cost overruns. These three cases generated a preliminary decision-making support figure reflecting the project management team's decision-making support. The decision-making support figure identified the drivers and challenges for the various degrees of modularity used for the different types of modules.

Documents	O&G sector Company A			Power Plant Company B	
	CS1OG	CS2OG	CS3OG	CS4PP	CS5PP
Project Description	√	√	√	√	√
Project Schedule	√	√	√	√	√
Monthly Reports	√	√	√	√	√
Bill of quantities	√	√	√	√	√
Project Specifications	√	√	√	√	√
Execution plan	√	√	NA	NA	NA
Project photos	√	√	√	√	√
Method Statements	√	√	√	√	√
Drawings	√	√	√	√	√

Fig. 1 Summary of case study documents collected

Case Study	Years of experience	No.	Decision-making support 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	√	√
CS4OG	10-20	7	X	√	√	X	√	√
CS5OG	10-20	5	X	√	√	X	√	√

Fig. 2 Case study participant's profile and interview topics

CS4PP and CS5PP assessed the possibility of applying these modularity decision-making support figures from O&G to another EC sector, in this case power plants.

Fig. 2 presents the interview participants profiles and interview topics investigated.

The project management team who participated in the decisions were interviewed more than once (Fig. 3) to ensure clarity and depth of data collected. In the first phase, each participant was interviewed for about 30 minutes. The interviews followed a set of questions derived from the literature and case study documents. Therefore, the need for the second phase of interviews was essential.

Module type	Midstream O&G sector			Power plant sector	
	Case 1 (CS1OG)	Case 2 (CS2OG)	Case 3 (CS3OG)	Case 4 (CS4PP)	Case 5 (CS5PP)
Pipe rack	6	7	0	5	3
Piping	5	0	3	2	3
Deck	5	4	3	0	0
Jackets	5	0	0	0	0
Equipment	4	0	3	3	2
Piles and pile caps	7	5	0	5	3
Walkways	2	0	3	0	0
Total number of interviews per case study	31	16	12	15	11

Fig. 3 Number of interviews in case studies for each module type

The need for an additional qualitative method to assess the case studies results was essential. Interviews with independent participants who were not involved in the case studies and were not employed by the case companies were, therefore, conducted. These interviews assisted in ensuring that the findings of the research could be more widely applicable.

Invitations for these secondary interviews were emailed to 24 experts working in industrial companies in the Middle East; 20 accepted (83% response). Interviews were conducted via telephone and Skype for 30 to 45 minutes. Eleven participants out of 20 were interviewed twice and two for three times.

Questions were designed into four sections: Participant profile, current decision support system for modularization in O&G and power plant projects, main drivers/criteria affecting the decision for the degree of modularization in O&G and power plants projects and main risks and barriers to consider in modularization.

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B. Data Analysis

Preliminary codes and categories were identified based on the data from CS1OG and the literature. The data collected were analysed thematically comprising four themes (steel structure, concrete structure, piping and equipment) and five categories (substructure, superstructure, vendor package equipment and vendor-assembled equipment and piping) (Fig 4).

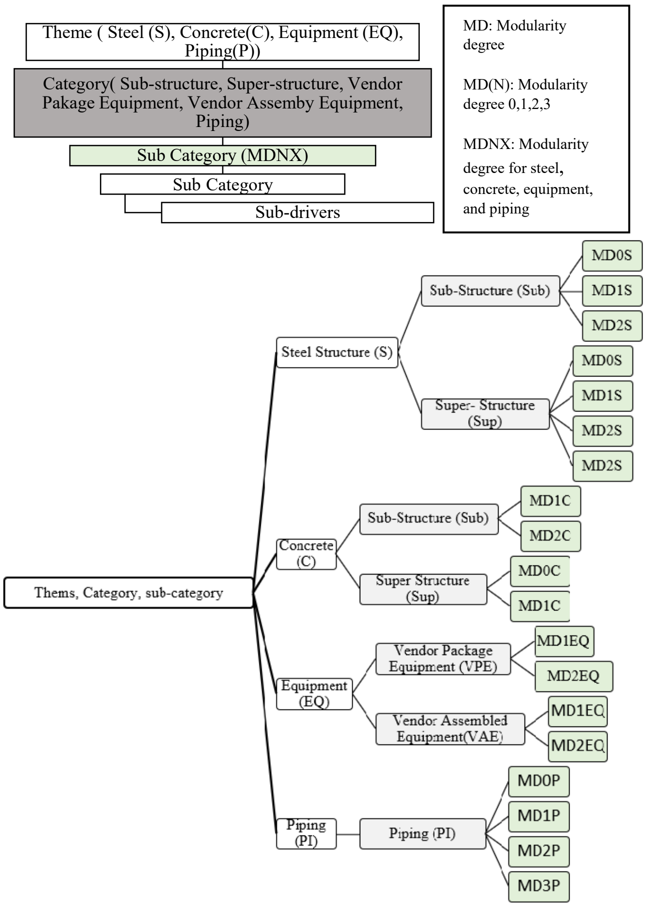

Fig. 4 Research analysis themes and categories

IV. RESULTS

According to the participants the degree of modularity is defined as the split of modularization activities, between the external fabricator (off-site) and fabrication activities in site location (process modularity), with respect to the design complexity and the amount of work to be fabricated in 3D or 2D (product modularity), considering the external fabricator or subsidiary company (organization modularity).

Before the project commences, the project team conducted a constructability meeting to determine the extent of modularization, in which the team examines the structural components (i.e., size, weight, length), the location of possible fabricators, roads logistics, transport regulations, and the associated costs incurred for the period until the modules arrive at site.

For the project team to optimize the use of modularization, factors such as design (engineering), safety, quality, transportation, site constraints, logistics, and process must be investigated, and the extend of modularization is determined.

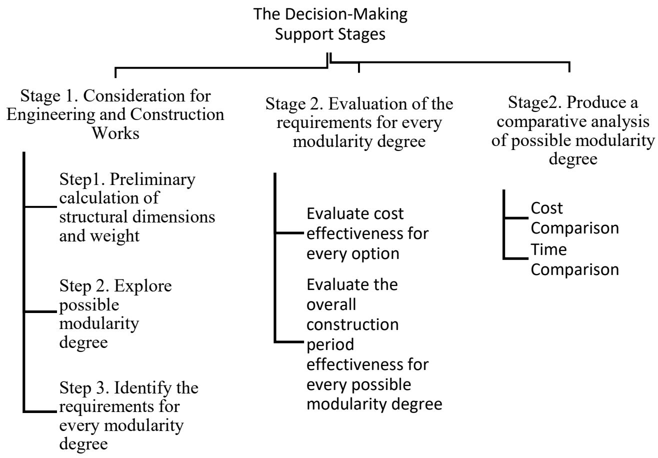

Fig. 5 The decision-making support stages for the choice of possible degree of modularity

In the first stage of Fig. 5, consideration of the engineering and construction activities, takes place through three sequential steps. In stage 1 (step 1), the preliminarily calculations of the structural dimensions and weight are made. In step 2, degrees of modularity are explored (Figs. 9-12) through weekly and monthly meetings of the project team. In step 3 of stage 1, the requirements of each construction method are identified from all project disciplines as follows: Design, site constraints, resources, productivity, quality, process, administration, transportation, and safety.

In stage 2, the project team calculated the cost associated for the different degrees of modularity, and a comparison evaluated.

Fig. 6 Jacket Module

The data required to decide on the degree of modularity are centred on nine key drivers within stage 3, and has been developed throughout this paper to reflect the decision-making support for the degree of modularity.

Each driver is then divided into sub-drivers as presented in Fig. 8. Following the path of each driver and sub driver, requirements for every degree of modularity are determined and a decision about the degree of modularity is taken (MD0, MD1, MD2 or MD3)

Fig. 7 Trestle Module

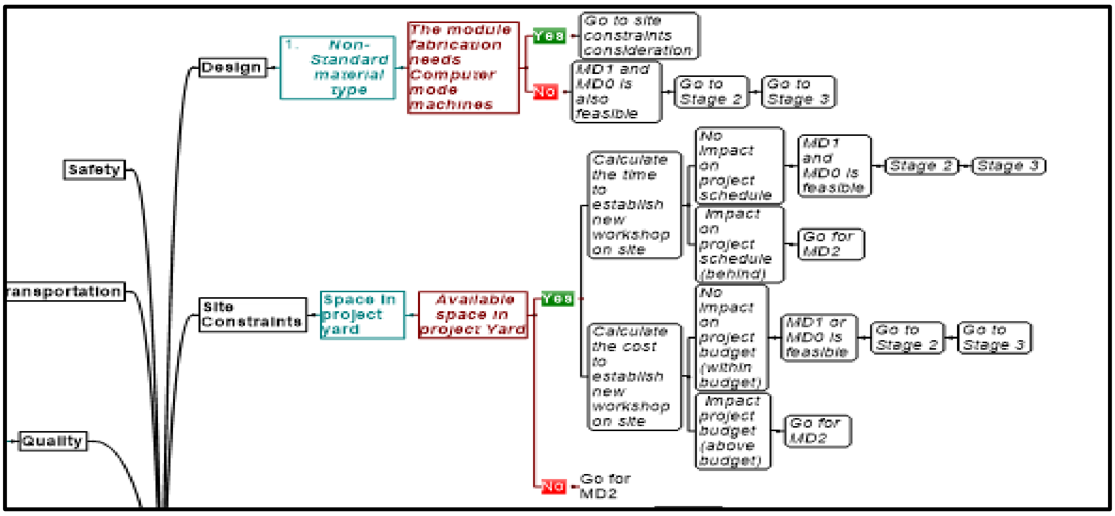

Fig. 8 Site constraints drivers

For example, as illustrated in Fig. 8, following the path of site constraints (key driver) and space in the project yard (as sub driver) depicted here, results show that structure modularization (MD2) is the most suitable option (if there is no available workshop in the project yard to fabricate the module or if establishing a new workshop has a negative impact on the project time and cost). However, MD0 and MD1 are feasible if the contractor has available space to establish a workshop with no impact on project time and cost. The paths followed by stage 2 and stage 3 are illustrated in Fig. 5.

In the second stage of the decision-making support for possible degree of modularity, the management team quantified the cost and time taken for every construction method. The time evaluation is done through developing different schedule programs with the possible degree of modularity. The details of this process (cost and time) are not part of this study.

In the third stage of the decision-making support, the project team produced a comparative analysis of the possible construction methods. After this third stage, the project team prioritized the effectiveness of the degree based on cost and time constraints.

A. Concept of Modularity

Modularization terms have been introduced that are based on product, process and organizational modularity. This is done by considering the complexity of civil, electrical and instrumentation design (product modularity), the process of manufacturing and fabrication, onshore/offshore installation (process modularity), and the organizational structure of the company and possible subsidiary company as a fabricator (organization modularity).

Based on the results, the *degree* of modularity has been defined as the split of modularization activities between the external fabricator (off-site) and the fabrication activities on the site location (process modularity). This also relates to the design complexity and the amount of work to be fabricated in either 3D or 2D dimensions (product modularity), as well as considering the external fabricator or subsidiary company (organizational modularity). Hence, the terms *process*, *product* and *organizational* modularity have been redefined into new terms, namely Degrees of Modularity 0, 1, 2 and 3.

Key Drivers for Modularization Vary Among Module Types

Based on the analysis of the three case studies and the assessment of 12 independent interviewees (not involved in the cases), the priority of the drivers to decide the degree of modularity for implementing degree of modularity 2S in the substructure and superstructures are:

- the module material type is not standard;
- necessary computer-based equipment is not available in the contractor's yard and is available in the fabricator's yard;
- setting up a workshop on-site would be time consuming;
- it is necessary to purchase equipment for the site workshop;
- this equipment would be idle after the project; there would be restrictions on the use of project land; and
- fabricators have a stable and skilled workforce in the module fabrication area.

The priority of the key drivers for implementing MD1 for the steel substructure and superstructure are:

- the full length of the module cannot be transported in a standard trailer;
- additional logistics are needed resulting in extra cost and time;
- marine transportation is time consuming;
- the weight and dimensions of the module could be fabricated or pre-assembled on-site; and
- the fabricator does not have enough laydown area to fabricate and store the module under study.

V. Findings and Contribution

Contrary to what has been published previously which is more generic, the key drivers deciding the degree of modularization vary according to module type. For example, for the jacket module, the key drivers to decide on MD2 are the complexity of the design, the non-standard material and the need for computerized machines that might not be available to the contractor on-site. In addition, jacket fabricators exist worldwide, specialized in fabricating the module. However, for piping, to avoid mixing the material at the fabricator site and to ensure full control over the quality, MD1 would be the only suitable method.

MD0 and MD1 are more applied than MD2 in EC projects in the Middle East. This paper suggests that if the weight and dimensions of the module allow the fabrication or pre-assembly of the module on-site, and the necessary equipment and labour is available, MD1 could be an option to consider. If the material is free issued by the client and shipped to the site, to avoid a mix of materials and facilitate easy identification of the different materials, MD1 could also be a suitable degree of modularity in preference to MD3.

However, for jacket modules MD2 is the only available option as the module material type is not standard and needs computer-based equipment that is only available in specialized fabricator yard.

A. Terminology for Modularity

This study introduces terminology to elucidate various degrees of modularity. It provides a comprehensive description of the activities and steps necessary for each degree of modularity. Figs. 9-13 detail all the steps needing to be executed as listed in the column titled ‘tasks’, and the amount of work to be executed (2D/3D) as listed in the column titled ‘degree for modularity, dimension/level of fabrication’. Such details are missing from the literature.

The following isi a brief description of the activities undertaken in degree of modularity 0, 1, 2 and 3 for steel structure (S) and concrete structures (C). For MD0S, the module is fabricated in 3D dimensions in the project laydown area. The corrosion protection and Electrical & Mechanical (EI) activities are installed offshore after all the modules are installed at their final location.

The degree of modularity 1S (MD1S): The pre-assembly in a 2D dimensional module is completed in a factory. The module is fabricated in 3D dimensions in the project laydown area. The corrosion and installation activities are executed offshore after all the modules are installed.

Tasks	**Degree of modularity 2D/3D (Split of modularization activities and module dimensions)**		
	Fabrication of the module in factory (2D/3D)	**Fabrication of module in 2D/3D dimension site yard (3D)**	**Final Location Activities (offshore or nearshore)**
Pre-assemblies of steel module	**X**	**√(3D)**	**X**
Test welds	**X**	**√(3D)**	**X**
Apply corrosion protection	**X**	**X**	**√(3D)**
Install pipework (if applicable)	**X**	**X**	**√**
Install electrical and control systems	**X**	**X**	**√**

Fig. 9 Degree of modularity 0S (MD0S)

Tasks	Degree of modularity (Split of modularization activities and module dimensions)		
	Fabrication of the module in factory (2D/3D)	Fabrication of module in 2D/3D dimension site yard (3D)	Final Location Activities (offshore or nearshore)
Module pre-assemblies	√(2D)	x	X
Module fabrication	x	√(3D)	X
Test welds	x	√(3D)	X
Apply corrosion protection	X	X	√(3D)
Install process pipework (if applicable)	X	X	√(3D)
Install electrical and control systems	X	X	√(3D)

Fig. 10 Degree of modularity 1S (MD1S)

The degree of modularity 2S (MD2S): The pre-assembly of the module in 3D dimensions takes place in the factory. The corrosion and EI installation activities are executed offshore after the modules have been installed.

Tasks	**Degree of modularity (Split of modularization activities and module dimensions)**		
	Fabrication of the module in factory (2D/3D)	**Fabrication of module in 2D/3D dimension site yard**	**Final Location Activities (offshore or nearshore)**
Module fabrication	**√ (3D)**	**X**	**X**
Test welds	**√(3D)**	**X**	**X**
Apply corrosion protection	**X**	**X**	**√(3D)**
Transport from supplier/fabricator factory to work site	**X**	**X**	**X**
Install process pipework (if applicable)	**X**	**X**	**√(3D)**
Install electrical and control systems	**X**	**X**	**√(3D)**

Fig. 11 Degree of modularity 2S (MD2S)

Tasks	**Degree of modularity (Split of modularization activities and module dimensions)**		
	Fabrication of the module in factory (2D/3D)	**Fabricatio n of module in 2D/3D dimension site yard (3D**	**Final location activities (offshore or nearshore)**
Pre-assemblies together to produce the structure of the whole module	**√(3D)**	**X**	**X**
Test welds	**√(3D)**	**X**	**X**
Apply corrosion protection	**√(3D)**	**X**	**X**
Install process pipework (if applicable)	**√(3D)**	**X**	**X**
Install electrical and Instrumentation works	**√(3D)**	**X**	**X**

Fig. 12 Degree of modularity 3S(MD3S)

The degree of modularity 3S (MD3S): The assembly of the module in 3D dimensions and EI installation takes place in the factory.

There is a limited number of decision support tools developed for the EC sector, hence a need for an up-to-date decision support tool and/or procedure that can cope with the growing complexity of the industry [5]. A decision-making support checklist has been developed for this paper, to support in determining the most appropriate degree of modularity. A decision-making support process figure has also been developed considering the system, component and traditional modularization, to help reflect the requirements of each modularity driver.

The research suggests that the decision-making support process to determine the degree of modularity has two phases. In phase 1, possible degrees of modularity are explored. The decision-making support checklist developed helps to determine the possible degree of modularity options for every module type. In phase 2, the requirements of each modularity are identified. The decision-making support figure developed in this research (Fig. 13) helps to determine the requirements of every driver that affect the degree of modularity, and to determine the implications of the decisions regarding modularization.

A. Decision-Making Support Checklist for Degree of Modularity Options

The decision-making support checklist (for O&G and power plants) assists decision-making support for the degree of modularity. This is achieved by quantifying and comparing the number of main drivers for every degree of modularity option. The check lists all the drivers affecting the decision-making support for modularization, by inserting the legend '√' corresponding to the drivers suitable to project circumstances, Fig. 13 calculates and provides the sub-total and total number of key drivers to support each modularity option. However, the decision-making support checklist considers the weight factor of all drivers as being equal.

As presented in Fig. 13, for the jackets modules as an example, there are 31 main drivers to support decisions for MD2, marked as √ in the column titled 'Structure modularization/Jackets, 14 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. Hence, the most suitable degree of modularity for jackets is MD2. Similarly, for pipe racks, 30 main drivers support a decision for MD 2 √ versus 28 main drivers supporting a decision for MD1, therefore, both options are suitable.

C. Decision-Making Figures for Modularization

This section explains the second phase of decision-making support for the degree of modularity, and explores the requirement of every degree of modularity. The drivers affecting decision-making support about the degree of modularity vary across EC sub-sectors and module types. A decision-making support figure has been developed as a result of the study, providing a rough evaluation for the feasible degree of modularity by assessing the impact of all the drivers on the degree of modularity. In doing this, the drivers can be evaluated using the path presented for them (Fig. 14).

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. 13 Summary of the check list results for all module types

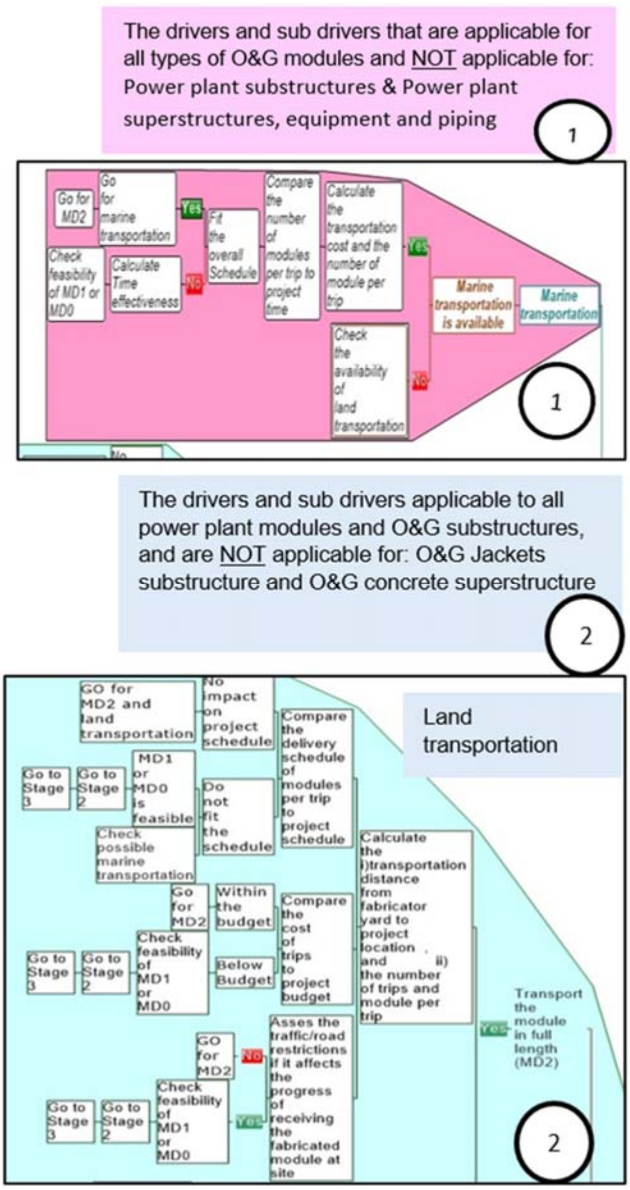

Fig. 14 Decision making support figure for modularization: transportation driver

The boxes explain the drivers and sub drivers of the boundary. The number and colour of the boxes are used to connect a box to the boundary. For example, grey box number 2 presents the grey boundary number 2. As stated in grey box number 2: "The drivers and sub drivers that affect the decision for modularization and applicable for O&G jackets and precast superstructure, but not applicable for other O&G and powerplants substructures and superstructures". These are explained in grey boundary number 2" Land transportation". Land transportation is not a transportation option to transport Jacket module or precast pile caps from fabricator yard to project location. However, it is a transportation option to transport powerplants superstructure modules. Marine transportation (red boundary number 1) is not an option or a driver to decide the degree of modularity to all powerplants substructure and superstructure, but a key driver to decide the degree of modularity for O&G modules (Red box number 1).

According to Fig. 14, "Transportation driver", the results suggest that if land transportation is the only option for a project, the user of the figure must first examine the possibility to transport the whole module from the fabricator yard to the project location (MD2). If transporting the whole module is an option (Legend: yes), then the user of the figure must calculate the distance, the number of trips and number of modules to be transported in each trip from fabricator yard to project location. If the number of modules to be delivered per trip in full dimensions complies with the overall project schedule (Legend: no impact on project schedule) and budget (Legend: no impact on project budget), then degree of modularity 2 is a suitable degree of modularity for the module under study. However, if the project schedule and cost are constraining factors and the number of modules to be transported delay the progress of the project, then the correct decision might be MD1 or MD0. Then, the user of the figure must calculate and compare the cost and time associated with degree of modularity 0 and degree of modularity 1 (MD0 and MD1) resulted from the land transportation driver to decide the suitable degree of modularity (Legend: go to stage 2).

Calculations of the road capacity is also required to ensure that it is suitable for transporting the whole module from the fabricator yard to the project location. If the module dimensions comply with the country logistics (i.e., road capacity and dimensions), then degree of modularity 2 is suitable. If the module dimensions do not comply with the country logistics, then the suitable modularity is degree of modularity 0 or degree of modularity1.

VI. Conclusions

A small number of researchers have investigated the decision-making support criteria for system to component modularization in EC projects. The literature published is concerned mainly with the upstream O&G sector, the power plant sector, or the EC sector as a whole. Previous studies also investigate European and USA contexts separately. However, the literature lacks an in-depth investigation, especially for the Middle East region. A comparison between the criteria for the drivers between the two sectors is therefore required. This research investigates this gap, contributing to the current body of knowledge in this area.

Very few studies provide models or processes for selecting construction systems, methods or materials. Those that do exist focus mainly on weighting and scoring processes, but are not clear on establishing the decision context, or justifying the criteria applied and the options considered. Furthermore, these studies focus mainly on the building sector, with little published regarding EC and more specifically O&G, including the downstream sector in the Middle East, hence the focus of this research.

The research contributes to current understanding of the concept of modularization by providing a workable definition of the degree of modularization (the split of works between the site and the workshop). This research has developed new terminology; the new terms introduced integrate process, product and organizational modularity by considering the complexity of civil and EI design (product modularity) and the process of manufacturing and fabrication, onshore/offshore installation (process modularity), and the organizational structure of the company and possible subsidiary company as a fabricator (organizational modularity). Hence, the updated definition of the degree of modularity introduced here is the split in the number of modularization activities between the external fabricator (offsite) and fabrication activities on the site location (process modularity), with respect to the design complexity and the amount of work to be fabricated in 3D or 2D dimensions (product modularity), considering the external fabricator or subsidiary company (organizational modularity). Therefore, the terms 'process', 'product' and 'organizational' modularity have been updated into new terms, namely Modularity Degrees 0, 1, 2 and 3.

This paper suggests that in the Middle East, applying MD0, MD1 and MD2 are more suitable than MD3, contrary to what was proposed by earlier studies stating that MD3 is the most suitable degree of modularization. Previous studies investigate European and USA contexts separately, lacking in-depth investigation and comparison to the important Middle East region. This research investigates this specific gap, producing a decision-making support checklist, which summarizes all the drivers and sub-drivers collected involved in the choice of a suitable degree of modularity. The decision-making support check list helps determine the possible options of degree of modularity for every module type in order to subsequently select the correct one.

The research has developed a decision-making support figure to assist in decision-making support regarding the extent of modularity showing structure, component and traditional modularization, and provides an evaluation for the suitable degree of modularity by calculating and comparing the number of key drivers that support each degree of modularity.

The key factors affecting decisions for modularization vary across EC sub-sectors and module types contrary to literature claiming that key drivers amongst EC sectors and modules are the same. This research has presented a decision-making support figure showing the differences in drivers across EC sub-sectors, and examined the validity of this strategy and its possible application to power plant projects.

VII. Implications

The literature review showed that there are very few studies examining tools or checklist for selecting the suitable degree of modularity in EC projects. A small number of researchers have investigated the decision criteria for system to component modularization in EC projects. This research recommends that the decision-making support figure for the degree of modularity and the decision-making support check list for modularity options could be used to support decision-making support for the degree of modularization in the O&G industry.

VII. Limitations and Future Research

The data were collected using qualitative research, in order to conduct an in-depth investigation of the drivers and barriers for the degree of modularization in EC. However, the research is limited to downstream and power project sub-sectors only and to three countries in the Middle East region (Egypt, UAE and Oman). Five case studies were carried out involving independent interviews. However, the case studies present the strategies of only two companies, Company A (CSNOG) and Company B (CSNPP). The independent interviews reflected the opinions of seven other companies.

This paper is concerned with decisions for modularization to enhance project delivery, in terms of time and cost only. However, the paper is limited to qualitative cost and time data. The comparative cost and time methods employed by the cases under study are not part of this research. Further, the decision-making support checklist developed in this research consider the drivers for modularization have equal weight factor.

It is important that research is continued into the use of modularization technologies in O&G and power plants so that further understanding can be gained and contributions made to realize the industry's aspirations for improving project delivery from the perspectives of time, cost, and quality. This study makes the following recommendations for future research:

The main contribution of this thesis is the development of a modern decision-making support strategy for the EC sector. However, further research could develop this strategy and serve to continuously update it in order to cope with market changes and industry innovations. Further research could test the process in different industrial scenarios, finding new impacts or leading to further modifications. More case studies on the use of modularization for the O&G sector could be conducted, potentially focusing on the integration of the modularization approach with technology such as BIM for decision- making on suitable degrees of modularization.

Future research could investigate a suitable time for an engineering design freeze and utilizing modularization technology. This study was based on the Middle East region. The extent to which the findings are fully applicable to the broader international EC market is unclear. Similar studies within the international context would be of interest to both academics and industry, given the increasing globalization of the economy and supply chains. These future studies could contribute further knowledge to understanding and optimizing the use of modularization in a global environment, while also providing valuable data to inform and benefit practice.

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